METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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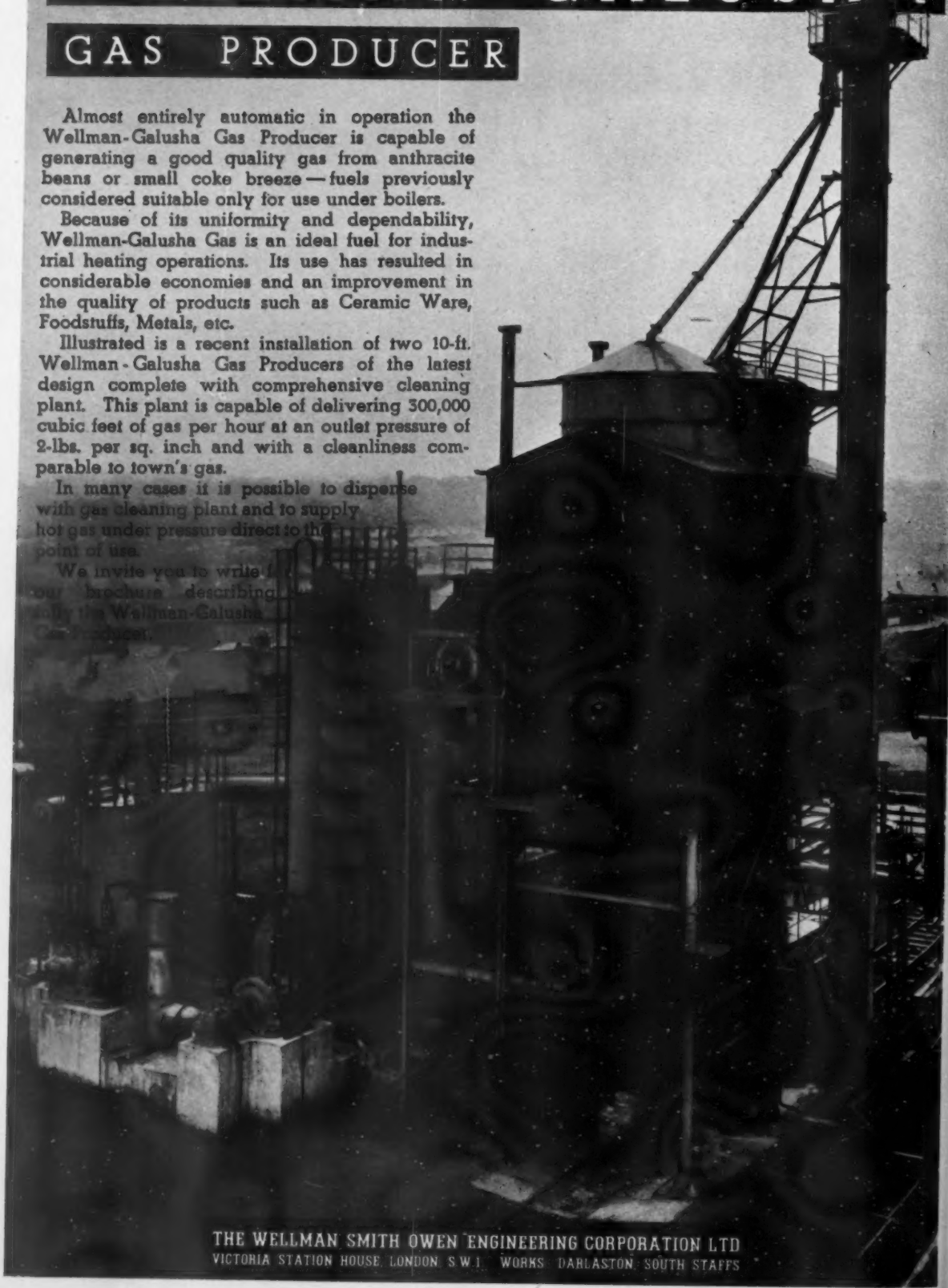

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METALLURGIA

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APRIL, 1947 VOL. XXXV No. 210

Economic Planning

THE recent fuel crisis has left the nation in no doubt as to the seriousness of Britain's economic position. An analysis of our problems and the resources available to cope with them have been presented in two Government documents. One emphasised the need for closer co-operation between all sections of industry and the other reviewed the economic outlook of the country for 1947 and stressed the urgency for action to restore economic stability. Numerous speeches were made in the House of Commons in the recent debates on the economic state of the nation, but the same ground was covered as has been covered many times since the war ended. Arising from the debate, however, there emerged a decision by the Government to strengthen its planning machinery. A new planning organisation has now been formed, with Sir Edwin Plowden as chief planning officer and Sir Robert Sinclair as a part-time industrial consultant, which is to cover the whole field of forward planning and to be specially concerned with the more immediate task of reviewing the programme for the rest of this year in the light of developing conditions.

It has been made clear by the Prime Minister that all decisions on planning policy will be made by the Cabinet and not by the chief planning officer. This, of course, follows the normal practice in industry, where the directors of a company make decisions on the plans placed before them by their various executives. From a national point of view the decisions will be made on a wider basis and will concern the best allocation of available man-power, materials, services and manufacturing capacity, but probably of greater importance is the direction of exports and imports which will be included in the decisions. According to Sir Stafford Cripps it is not the intention of the Government to force exports into different markets by an extension of export licensing or other controls, but it is likely that under Government guidance there will be a deliberate effort by manufacturers and exporters to exercise the widest selection between possible markets in the light of the country's great need for certain currencies. An objective of great importance, for instance, is an increase in Britain's exports to the Western Hemisphere, however, it is not less important that other countries that have taken our products for a great number of years should not be neglected, least of all our friends in the Commonwealth and Empire.

The opinion is frequently expressed that Britain is taking a long time to effect changes to meet peace-time conditions. When it is remembered that the changes necessary to raise production during the war to satisfy the needs of the Forces occupied about five years, it will be appreciated that such criticism is unfair. The problems of post-war recovery are more complex and the same singleness of purpose is not operating; it would seem, therefore, that recovery on a sound basis will involve several years persistent hard work.

It is doubtful whether it is yet fully realised that the task of export is Britain's number one priority. At the moment it seems that we live to export, and the living is hard, but we must always bear in mind that we export to live. There seems no doubt that with many people the growing complexity of the economic orders has obscured the simple truths of international trade; they regard exports as a foolish sacrifice of domestic standards and imports as a threat to British labour. But exports are, in fact, the only real international currency, and Britain needs currency to buy her food and clothing and the raw materials for her industries. Real wealth will not return to Britain unless we can pay our way. This need of attaining a balance of payments overseas and the urgent need to improve supplies for our own people in the home market provides a constant tug-of-war, and it is not yet clear to many people that the sum total of these demands exceeds our capacity to produce, both from the point of view of labour and materials. It is the Government's duty, therefore, as the only body capable of taking a broad overall view, to endeavour to hold a wise balance between these two opposing forces; this can only be done by careful and wise planning.

But however well exports and imports are planned in an effort to bring about a balance we must retain sufficient raw materials to satisfy our own immediate needs before we can allow it to go into exports. We have already experienced difficulties as a result of the coal crisis, and it is likely that repercussions during the next few months will cause the export expansion to suffer seriously from this shortage. It will be necessary to curtail the use of several raw materials for export purposes, where the demands conflict with more urgent home requirements. Steel for products to be exported has already been cut severely so as not to hold up the house and factory building programme and to allow sufficient for home demands for machinery of all kinds, including that for the mines, for agriculture and transport. We cannot produce enough steel to satisfy our heavy requirements.

Another factor must always be kept in mind if planning is to be successful, it is the general apathy and lack of will to work really hard. This provides one of the most formidable problems operating against speedy recovery. Whether the effects of the recent crisis will cause employers and workers to realise the pressing need for co-operation and team work in effecting a solution it is probably too early to say. That there is need for vigorous action to stimulate a national effort few will deny. No amount of planning will effect a change of this kind, however good the intentions it is a problem for each individual to solve by recognising the gravity of Britain's need and by applying all possible efforts to meet it.

Social Aspects of Engineering

IN a symposium on the above subject presented at the Thirty-fourth Indian Science Congress recently held in Delhi, Mr. P. H. Kutar, general superintendent of Tata Iron & Steel Co. Ltd., delivered an opening address at the annual session of the Sub-Committee on Science and its Social Relations in which he said that it is the reflection of the ideal that engineers are dealing not only with material and natural forces but with and for human beings. At the outset he reviewed briefly the applications of science in promoting the material welfare of mankind, and pointed out that a significant measure of human progress is the increase in use of power and the better conversion of bodily energy into reasonable thinking instead of brute force or wishful theorising. Failure to recognise the intelligent use of dynamic resources as the basis of permanent civilised progress accounts for many of the haphazard and ineffective plans and actions of men.

Before the days of engineering, he said, man's tools were associated with the use of muscular energy. During the thousands of years preceding the Christian era, man's progress was exceedingly slow as far as the use of external power was concerned, but this did not necessarily imply that man was not developing in other ways; India, in particular, had developed a high level of civilisation. Astonishing developments had been made in the sciences of mathematics, astronomy, chemistry and medicine, side by side with development of schools of philosophy; but the fact remains that India did not follow up this development of early times. In the case of the Egyptians, Greeks and Romans too, history records great developments in many sciences, including hydraulics, mechanics, mathematics, astronomy, chemistry and medicine.

Mr. Kutar pictured development from early times to show how social forces can clip the wings of technological progress, and in continuing he outlined the next phase in man's rise in the use of power, in the development of which lay the foundation of the machine age. A fundamental change in the pattern of living was brought about by the "industrial revolution," from which emerged two contrasting sections of society, one based upon a very simple order of agriculture and hand labour and the other making great use of machinery. He made no effort to enumerate the new inventions and new uses of power which transpired from the period of industrial revolution other than to say that a thousand and one machines and devices were created, and from wireless to television and radar, from balloons to jet planes, the progress continues.

The recent war stepped up the tempo of the application of science by the demand for munitions, the need to devise means of dealing with novel weapons of attack and the problem of providing the necessaries of life for the civil as well as the military population. Since August 6th, 1945, a new source of power has shot into the civilised world, the power of atomic or nuclear energy. The proposed uses of this energy range from automotive power plants, through ship propulsion to interplanetary rockets. Which of these possible applications of nuclear energy is likely to become practical, and when, depends upon the amount of research, development and engineering effort which can be devoted to these physical factors in the immediate future.

The increase in the use of power and machinery brought, with its benefits, economic and social problems not easy of solution. In the first flush of enthusiasm for technical progress, the industrial pioneers overlooked the fact that all production and all progress must promote human welfare. Social and economic forces changed rapidly as a result of the more fundamental and productive forces of the machine. Many feared the final outcome of man's glorification of mechanisation, and while there was undoubtedly some justification for the criticisms levelled at what became known as the machine age, the introduction of machinery has brought many benefits to mankind, and, with the solution of social problems arising from changing environment brought about by the increased availability of energy, technical progress will continue to make this a better, more comfortable, safer and happier world. Engineers have an opportunity to lend a helping hand in the solution of social and economic problems.

Mr. Kutar referred to the problem of machinery as the direct preoccupation of engineers, and the problem of materials as concerning them directly and indirectly and which in turn largely influences the destiny of nations. But while the engineer's problem in machine design is to secure stability of structure, efficiency, and reliability in operation, the smooth motion and decreased loss from friction, highly desirable in machines, should also be sought after in human relations.

There is much constructive work to be done to make our communities better places in which to live, in which to enjoy the benefits of better living and to give assurance of work and leisure, that it becomes a common task to which engineers, psychologists and other scientific groups must continue to co-operate. There is an increasing recognition of social well-being as the true object of industry and mankind has a right to look to engineers, with their training in accuracy and truth, not only for leadership in industry but for the achievement of this objective.

British Industries Fair

THE British Industries Fair, which is to be held on May 5th to 16th simultaneously in London (at Earl's Court and Olympia) and in Birmingham (at Castle Bromwich), is receiving remarkable support from industry, in view of the fact that it is being held after only 21 months of peace. First held in 1915 to encourage the manufacture in the United Kingdom of products which had previously been imported from foreign sources, by 1939 this Fair had become established as the greatest commercial event in the Empire and a most important contribution to international trade.

This Trade Fair serves a far wider purpose than the immediate placing of orders; overseas buyers will be able to consider Britain's industrial recovery from difficulties encountered, and obtain some idea of the success so far achieved, in relation to parallel difficulties throughout the world. They will be in a position to discuss production problems with the actual manufacturer. Old friendships will be renewed, and new contacts made while reviewing the many unique advances in industrial technique which have resulted from experience gained in war. In some cases buyers will see innovations before they can be produced in quantity, and it is doubtful whether any previous Fair in this country has offered the overseas buyer so many developments as will be seen and discussed with manufacturers at the forthcoming Fair.

A Survey of Precision Casting

By J. N. Read

Metallurgists will be called upon to face new problems of alloy treatment as precision-casting methods, using silicon ester bonded refractories, become more widely and specially used in general foundry practice. This article, however is not concerned with the metallurgical aspects, but rather with the outline of the foundry technique of the processes, the working limits and progress difficulties, and a survey of present-day production and expected applications.

"PRECISION casting can be produced to limits of ± 0·002 with an extremely fine surface finish eliminating entirely the necessity for further machining operations upon the working faces." This claim was made in 1943 in connection with the Austenal[1] or "lost-wax" process. Since then, samples of practically every kind of alloy, from high-pouring temperature (1,480°–1,650° C.) chromium/cobalt/ molybdenum/tungsten,* tool and stainless steels—aluminium/manganese brasses and bronzes—to aluminium alloys have been tried to this specification. Already masses of attractive and decorative information have been publicised, in the safe knowledge that the process operates in a restrictive atmosphere of competitive secrecy. The time is ripe, therefore, to attempt to bring the whole subject into the light of day and commercial reality.

The "lost-wax" processes provide a logical introduction to the study of precision casting, because all future developed processes will make use of the same equipment, basic raw materials and production-flow methods.

Fig. 1 shows diagrammatically the "lost-wax" process, and it will be seen that the first operation is the making of a die for the wax pattern. The master oversize pattern is made of wood or metal, usually brass, and is mounted up to a parting line in plaster of paris or some such material. Ingates and locating flanges are incorporated. The pattern box is then built up, and Bi/Sn 70/30 poured into this at 170° F. Pressure may be exerted to increase the definition. The second half of the die can be poured with a lower melting point alloy on to the first impression, into which the pattern has been transferred. The two complimentary low melting point metal dies are dressed, and in order to prevent spread they are fitted into a steel-hinged book jacket by means of screws. The pattern is then removed and an $\frac{1}{8}$ in. injection hole, with location ring, drilled in a suitable position.

The pattern needs extra large feeding heads and risers, because otherwise the slow rate of metal-cooling results in hot tears. In multiple pattern dies it is as well to include test shape patterns, so that metallurgical testing can be subsequently carried out for a whole sprue batches. The die surfaces and injection hole are cleaned and lubricated with a rag or brush dipped in carbon tetrachloride or trichlorethylene to prevent

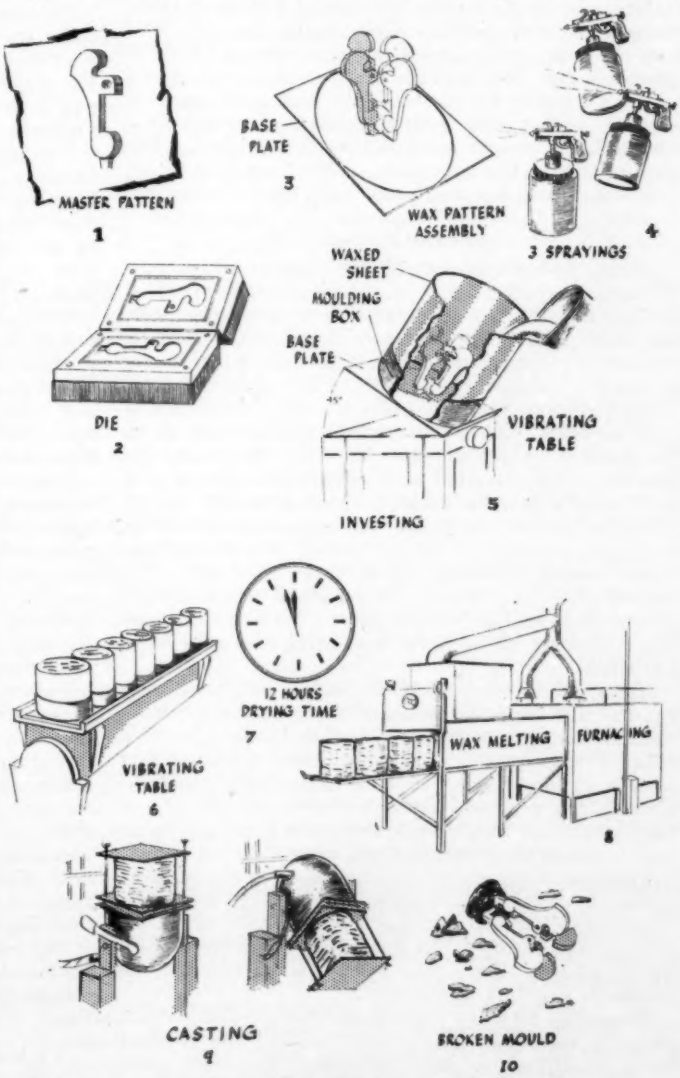


Fig. 1.—A series of drawings illustrating the "lost wax" process progressively.

* In particular Vitallium, Nimonic, Crown Max. alloys.

1. B.P.418160,454881. Austenal Laboratories Inc. New York.

wax adhesion, and the die closed ready for the next filling.

The Wax Pattern

The wax is melted in a thermostatically controlled water jacketed bath or vessel. The prepared die is filled through the injection hole, either by means of a syringe full of molten wax, or by an injection chamber, which can be incorporated in a machine for mass-production wax melting. Rapid solidification is helped by placing the die in a refrigerator.

As the wax determines the accuracy of the moulding, it must have flowability to take intricate definition when in the molten state, and yet harden with the minimum contraction. In the cold-set state strength is needed to resist distortion in subsequent handling, spray coating and vibro-investing. Sometimes tempering in ceramic dies is resorted to, in order to release wax contractional internal stresses.

The next operation after stripping the cold-set wax patterns, or line of patterns, is to assemble them together conveniently for casting. Girls firstly trim off flash from the edges with a small chisel or knife and inspect dimensionally. The patterns can then be joined on to a large wax ingate by momentarily melting them at a point of contact with a dental spatula, warmed in a bunsen flame, or with an electric-soldering pencil. The large ingates on the assemblies enable them to be stuck on to a moulding box-base plate ready for spray coating.

Spray Coating

In order to wet the relatively soft slippery wax pattern surface a soap solution† is required. To this is added sodium silicate, the accelerator or hydrochloric acid, and solid filler. The mixture is sprayed within 30 minutes of preparation, at a pressure from 30–80 lb./sq. in., using a standard type spray gun in a spraying booth.

The first coat needs to provide a close resilient and refractory film, and the best refractory filler resistant to the metal to be poured, must be chosen from amongst zirconia, silica, alumina and sillimanite. The second coat usually packs a backing of silica, owing to this having a smaller coefficient of expansion and better insulation, whilst the third coat merely acts as roughage on the outside surface to key the investment mix. The desired chemical reaction is, sodium silicate with hydrochloric acid in solution gives sodium chloride and silicic acid gel, which under heat breaks down to water and silica.

Silicon esters can be used instead of sodium silicate, but the wetting agent would have to be changed to a suitable solvent, such as methylated spirit, with a complete alteration in the nature of the spray. Ethyl silicate, in the presence of water containing a trace of hydrochloric acid, and dissolved in a mutual solvent such as alcohol forms silicic acid, which in turn under heat becomes adhesive silica and water.

These reactions should not be taken as representing actual hydrolysis mechanisms, but only indicating relationship between starting and end products.

Sodium silicate is cheap, but causes a lower refractory figure, whereas the silicon ester reaction used to be unreliable and very complex.

Practically all spray coatings defy production consistency, as atmospheric, chemical, physical and thermal shock conditions are daily variables. The main upset of these variations is probably the fact that the cold-set coatings will be subject to the vagaries of the formation of the colloidal silica bond, which, owing to it being a gel, cannot be easily examined by visual or physical micro inspection.

Recent investigations, however, point to the improved control of hydrolysis, or formation of the silicic acid gel, by the use of esters to which has been added a condensing agent.‡ This causes the ester to function, irrespective of extraneous conditions, and simplifies and speeds up the hydrolysis. These modified esters will be discussed in detail in the next article entitled, "Applications of Silicon Esters to Refractory Moulds and Coatings."

Investing Shop

Sprayed assemblies should pass, as soon as dry, to the investing shop, otherwise their storage should be in a controlled temperature and pressure to avoid any distortion.

The assembly is already attached to the base plate, and a moulding box with inside tapered walls is fitted on so that this stands about an inch above the pattern. The walls are further built up with asbestos or stiff waxed sheet to just over twice the height of the box. Fixing is by fusing the joints with wax.

The principle of the investment mix is based upon the fact that ethyl silicate or silicon ester liquid, when hydrolised to silicic acid gel, will bond a refractory filler into a cold hard set mass, which will remain bonded by the silica formed in the breakdown of the gel at a heat of over 700° C. There are several hydrolysis methods,[2] but the subject is too complex to discuss even briefly. It will be understood, nevertheless, that unless the particle packing is homogeneous the silicic acid gel will be unevenly distributed. The gel is composed of silica and water, which is the volatile content, and when the mould is baked internal stresses result from the variable silica bond, and mould distortion from the uneven water evaporation.

Originally the assembly was invested in a fine mixture of condensed ethyl silicate, hydrochloric acid, methylated spirit and water, together with silica flour, sand and magnesia, followed by topping up with a coarser grog mix of the same ingredients. The whole was vibrated until the heavy particles displaced the fines by gravity and the mix was considered to have acquired reasonable uniformity, porosity and crushing strength. The theory of an excess of liquid being required for particles to orientate themselves freely is reversed by more recent experience, which indicates that the right proportion of filler sizes will bed together uniformly in comparatively little liquid and in a shorter time. With more and more reliance being placed upon the efficient refractoriness of the spray coating, the filler merely becomes a support. Provided the commercial gradings are very consistent and do not contain impurities harmful to the refractoriness of the mass, the filler can be anything from sillimanite,§ alumina, foundry sands, or even fireclay grogs. (See Fig. 2.)

The existing popular investment technique is to place the moulding box on a tilted vibrating table, which in certain types rotates around a vertical axis at the same time. This ensures that, whilst the moulding box is

† Thos. Hedley & Sons, Ltd., Newcastle-upon-Tyne.

‡ P. B. Sillimanite Co., Ltd., London, N.W. 10.

§ Silesters manufactured by Silicon (Organic) Developments, Ltd.

2. Shaw and Hackford. *Ind. Chem.* 1945. XXI, 130.

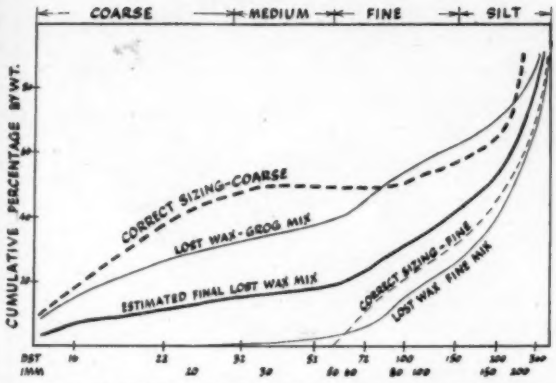


Fig. 2.—Precision casting investment mixes—sillimanite.

being filled, the under surfaces of the assembly will be tilted in every direction in order to release entrapped air. After topping the assembly with the mix, the mould is transferred to a long jigging table, where it is completely filled up. Vibration continues for 30 to 50 minutes or more depending on the mould bulk, and as the mix settles any excess liquid is poured off from the top. Settling of the investment is tested by dipping a stick into it until the mix begins to feel firm. The whole mould is then removed from the table and the top strickled off to about 1½ in. from the top of the wax pattern. Air drying for 12 hours follows for the mix to fully harden.

The development of investment mix compositions would appear to be one of the more satisfactory problems, but cheapening and reusing of the filler, together with the probable use of esters, containing a condensing agent, can still improve production.

Mould Baking and Casting

Preliminarily to baking, the moulds are stripped from the boxes, and asbestos or paper walls, with the use of a blow lamp on the wax jointing. To retain the wax American firms steam out the patterns, but preheating in an oxidising atmosphere in a core oven on mesh trays, or at the mouth of a tunnel furnace prior to the full baking cycle of 3–5 hours rising to 1,000° C., will be all that is done commercially. The slower the heating the better, since large quantities of methylated spirit up to 240° C., followed by water up to 600° C., must be forced out of the mould, and, of course, the silica has to revert from the colloidal state to crystalline at a temperature believed to begin at 575° C., but more likely to accelerate after 700° C.

Special arc furnaces have been designed for the high melting point alloys cast in the process, and these usually have a small capacity up to 10 lb., although larger furnaces are contemplated. When the metal is ready, the mould is clamped on the top of the furnace by means of a bracket, and with an asbestos gasket around the pouring hole. The furnace is tilted over, and in some cases air pressure applied from a pipeline, since the atmosphere is normally reducing. Centrifugal casting can also be used. When the metal has set the mould is smashed, the casting sandblasted with a fine sand and fettled with an abrasive wheel. Inspection follows either before heat-treatment or machining operations are commenced. A sand-blasted casting should compare with a die-cast finish.

Working Limits

Whatever is said about this subject provokes argument, and is likely to continue to do so as long as engineers specify precision limits without a proper reason or understanding of what limits are actually required, and the possibility of their being adhered to. By taking the "lost-wax" process by operations the limits to be expected can be estimated.

Low melting point cast dies are only possible to ± 0·001 per in., and are liable to surface distortion due to the hot-wax filling. For this reason some firms prefer to make steel dies by direct tooling to ± 0·002 overall. These dies have to include allowances for the wax, the mould, and the metal contraction.

The wax being repeatedly reused must be periodically checked, and new wax added to keep the properties constant. The maximum coefficient of expansion should not exceed 0·001 per ° C. Sagging and distortion of the patterns are the greatest difficulty, and with only one possible pattern inspection after the die stripping, great care must be exercised not to handle working faces during assembling and spraying. It is enough to add that workers are human and the weather temperamental!

Spray coatings drastically affect the surface finish, and, as already mentioned, are subject to all the vagaries of the ester hydrolysis. However, mostly due to close control, such great improvements have been made in establishing very fine and literally self-supporting coatings that there is a tendency to consider the investment mix of secondary importance. Against this must be offset the recent knowledge of correct filler sizing enabling the pattern to be immediately invested, and doing away with the whole delicate and expensive spraying operation.

The investment mix contracts 0·007–0·010 per in., from the poured to the 1,000° C. baked state, according to the composition. A variation of ±0·003 may occur in the same mould if the mix has not settled uniformly.

Assuming a metal contraction of 0·025 per in. On a pouring temperature of 1,500° C., ± 60° C., will equal ± 0·001, and therefore a sensitive fused silica sheathed immersion pyrometer is necessary to accurately measure the melt temperature.

Couple the human and weather treatment of the wax, together with die, mould and metal tolerances, a 3-in. narrow pattern could just be limited to ± 0·005, although in practice with irregular and weak cross-sectional areas ± 0·010 is more likely. High-melting point alloys can only be ground, and it is a good habit, therefore, to express limits as—0 +0·004 or 0·005, which is all that should be claimed per inch for general average production, with the proviso that ± 0·003 is the minimum of any limit.

Naturally, accuracy is only maintained by the closest production control, and exacting attention and examination to detail through progress card records.

Present-day Production and Future Applications

[3]In 1943 the American War Production Board addressed over 200 representatives of foundry firms on the Austenal "lost-wax" process. In two years their Government, Watervliet Arsenal pioneered 40,000 gun-mechanism parts of many different items. One firm made 25,000,000 super-charger bucket blades, with a monthly record output of 2,100,000, and another produced 4,000,000 castings of 400 different parts in 35

3. Precision Casting. *Iron Age*. New York, 17, N.Y.

different alloys. The late Henry Ford had a disabled men's training college casting all sorts of cutting tools from remelted scrap high-speed steel.

In this country about a dozen firms have experimented, mostly unsuccessfully, with the process, but a few are confident that production of at least 2,000 components per week will be worth while, in the limited application of jet engine turbine blades. So far as is known, only one firm contemplates a varied commercial production of intricately shaped components, mostly in stainless steel, which they estimate will cost less than standard manufacturing methods, and will allow them to forge ahead without delay of pre-tooling. (See Fig. 3). They will operate a new, much simpler, process obviating the necessity for a wax pattern. Plant and equipment would seem to cost about £3,000 to £4,000 for a production-foundry unit.

Fig. 3.—A typical commercial stainless steel precision casting of a standard 2 in. pipe union as cast by the alternative method to the "lost wax" process.

Precision-casting methods are not just scientific toys but scientific foundry processes. Provided a pattern can be made, jewellery, surgical and precision-instrument parts, small dies for diecasting, high-speed steel cutters, and any component from a $\frac{1}{4}$ oz. to $\frac{1}{2}$ lb. in any known alloy can be cast to $\pm 0{\cdot}005$ per in. After heat-treatment, components will be comparable to the average forging, die-cast or machined block, and the less the numbers required the greater the saving in time and cost.

Instrumentation of Open-Hearth Steel-making Furnaces

FOR new steelmaking installations and the modernisation of existing installations, the Open-hearth Instrument Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association suggests the following list of control instruments. Items starred are considered essential to the proper working of the furnace: the remaining items are considered to be desirable, and it is recommended that the instruments be used in the following way:—

*1. The gas main pressure control to be fixed at a pressure that will ensure the maximum quantity of gas that will be wanted at any time passing the valve-to-port resistance.

*2. The gas meter to be used to show the maximum quantity of gas which the melting shop manager considers can be burned in the furnace. He will order this quantity not to be exceeded. This will be referred to as the maximum gas flow. Apart from this the gas meter will merely be used to record what has happened. The gas flow is not itself regulated to a constant value, but is controlled so as to produce the required conditions of roof and/or steel temperature in the furnace.

*3. The air meter will be used to control the air flow to that which the melting shop manager thinks best to burn the gas.

*4. The furnace will be so designed that at maximum gas flow a specified pressure will be attained at the top of the gas checker. An increase in this pressure at maximum gas flow indicates the making up of the gas port and shows that the port has to be opened up. This maximum gas-flow pressure must be kept constant.

*5. The draught gauge will act merely as a recorder of what is happening and will take no part in the regulation of the furnace.

*6 and 7. The furnace pressure will be controlled either manually or automatically (normally by means of the stack damper) so that under all conditions of gas flow and the correct associated air flow the pressure in the furnace is that which the melting shop manager wants.

8. The producer will be run so that the CO_2 recorder always reads below, say, 5%.

*9. The gas supply is to be kept rigidly at the maximum gas flow until the maximum safe operating temperature shown on the roof temperature instrument is reached. Thereafter it will be constantly adjusted either according to the roof temperature or according to the temperature of the liquid steel.

10. The chequer temperature instrument can be used for:—

(*a*) Protection against overheating of the chambers.
(*b*) Information.
(*c*) Reversal, if the melting shop manager likes this method.

11. The time signal should be set so as to give a signal at such time after last reversal that the melting shop manager likes. It is an alternative method of reversal to temperature reversal.

*12. The immersion pyrometer will be used to fix, along with the carbon content, the time ore feeding should commence and its subsequent rate. It will also be used for controlling tapping temperatures.

The Manufacture of Magnesium Sand Castings

Inspection for Soundness, Structure and Dimensions

By G. B. Partridge, A.I.M.

Production Metallurgist, Elektron Foundry, Birmingham Aluminium Castings (1903) Co. Ltd.

Following cleaning and before being despatched, magnesium castings are given a very thorough inspection which embraces examination for surface flaws and cracks, dimensional checking, X-ray inspection by radiography, metallographic examination for grain size and heat treatment efficiency, and a fracture test is carried out on a percentage of castings produced basis in special cases, when called for by the customer. The whole process is discussed in a practical manner.

AFTER the poured castings have cooled sufficiently they are knocked out of the moulding boxes on a vibratory shake-out and the cores removed by pneumatic hammer and chisel. The benefits of careful sand control are now realised, for refractory cores present a costly and difficult bottleneck, exaggerated by the low heat content of the magnesium alloys. Occasionally some runners are detached during knock-out but in the majority of cases the casting with its runners and risers still intact is passed into the fettling shop.

The cost of manufacture of a part is consideraby increased if difficult, and therefore expensive dressing operations are necessary to give the casting a good finish and, whilst the major consideration of the foundry management should be to produce a sound casting, careful consideration of the positioning of excess metal in the form of risers, which have to be subsequently removed, will be amply repaid by quicker turnout and lower overhead cost of the fettling shop. In some American factories which have their own magnesium foundries it is the policy to so arrange the risers that they are easily removed during the first machining operation proper.

The usual practice is to remove the runners and the bulk of the riser metal by vertical or horizontal band saws, final fettling operations being done by pneumatic chisels, filing and grinding; kellering and scurfing is also used. If a large quantity of big castings of one type is called for, special jigs are made for use when sawing, etc., to expedite the work through the shop and risers of large cross section are sometimes parted off in preference to sawing.

Shot blasting is a very important operation and has great value in detecting surface scum or oxidation troubles, all castings being so treated before inspection. The latest process specification[1] dealing with the protection of magnesium alloys against corrosion states that such a cleaning process as grit blasting lowers the corrosion resistance of the alloys and should either be avoided or followed by scurfing or machining, indeed, grit blasting of high purity alloys is prohibited unless machining to 0·040 in. all over automatically follows. However, grit blasting is so convenient and helpful to the foundry that its abolition in favour of other methods seems doubtful. Mention must be made of the interest shown during the last few years in the hydroblast method of cleansing castings, which consists of directing a powerful jet of water and sand against cores, etc., by means of a hand gun; this method automatically knocks out and cleans the surface of castings for inspection.

With the exception of the grinding operation no special precautions are necessary during the handling of the castings through the dressing shop and all chippings and flash are melted down and ingoted for subsequent use as recovered process scrap. The fire hazard is serious with finely divided material such as grindings, and all grinding machines are located on an outside wall with exhausts connected to a wet drenching chamber outside; the accumulated sludge is removed frequently and burnt in an incinerator. A warning lamp gives indication of failure of the exhaust apparatus and, in the event of such a happening, work ceases at once; grinding of tools or other iron or steel articles is prohibited on these machines as a spark is a source of danger.

Visual Inspection

Through continuous practice the operators in the fettling shop are all fairly sharp eyed, and it will be realised that if a casting has an obvious defect it is noticed at an early stage and no further work is done upon it until examined by the shop foreman, who decides what is to be done.

As shot blasting is so useful in the detection of hidden surface defects it sometimes happens that this operation is done immediately after the sawing off of risers, etc., but the sequence of fettling and cleaning operations is decided by the shop foreman as he thinks fit. Should no defect have been noticed the casting will continue to be fettled until it reaches the viewing stage, whereupon a close scrutiny of all parts of the casting is made for surface defects. and cracks. Cracks do not usually present a problem in magnesium sand castings, but a cheap and efficient method for their detection is the paraffin-chalk test, which consists of applying paraffin to the surface of the casting, wiping away the surplus and dusting with powdered chalk; any residual paraffin located in cracks or coarse porosity works out and shows up against the white background.

Dimensional inspection of castings is carried out by the use of jigs and gauges in conjunction with steel machined tables, metal thicknesses being checked by means of calipers. Repetition jobs frequently have their jigs set up permanently so that the castings can easily be placed in position and rapidly checked over by the necessary gauges accurately made by the central inspection dept. Sample castings are usually given a complete "marking off" to the drawing and this precaution obviates unnecessary waste of time and scrap

Fig. 1. Radiologist examining films in a viewing room blacked out to give ideal subjective conditions.

Fig. 2.—Setting up a casting preparatory to taking an X-ray shot.

at a later date, but a complete machining operation by the customer is the best safeguard.

Pressure Tightness

The nature of some parts of a machine automatically calls for pressure tightness and some castings are required to withstand severe pressures. It is most important that the major functions of a casting should be stated upon the drawing, for castings that have to withstand pressures require well thought out technique, and are not always produced first time. Micro-porosity is the usual cause of a leaky casting and all parts which call for pressure tightness are tested by pumping air into the chambers of the casting, after sealing all openings with rubber washers and immersing in a tank of water; any signs of a stream of bubbles tells its own tale. Many forms of impregnation are used to seal leaks in castings and more are being suggested, especially in America, but it seems reasonable that the money which has to be spent on these fancy remedies would be put to better use if paid to first class foundry technicians to produce a non-porous casting. For the organic chemist to spend his time developing fillers of this type instead of producing organic compounds useful in themselves seems prostitution of the science of organic chemistry.

1 D.T.D. 911 A. November, 1946.
2 C. J. Bushrod, M.Sc., "Magnesium base alloys. Practical value of protective treatments." *Magnesium Review and Abstracts*, Vol. III, 5.
3 W. S. Loose, "Corrosion and protection of magnesium." American Society for Metals, 1946.

Protective Coatings

Some castings are covered by specifications which call for X-ray inspection and some are required in one of the various heat-treated conditions, but before describing these processes, which warrant separate consideration, it will be as well to describe the final operation in the fettling shop, which consists of the application of chemical protective coating. This coating is applied for two reasons (*a*) to protect and confer increased corrosion resistance on the magnesium alloys; (*b*) to provide a suitable base for subsequent paint protection.

Before treating castings it is necessary to have them free from grease and dirt and this is best accomplished either by a preliminary dip in 2 per cent caustic soda or by lightly shot blasting. Two baths are in regular use in this country and are listed in Table I, the first known as the acid golden chromate, was developed by the I. G. Farben and castings are immersed in the cold solution from 30 seconds to about 2 minutes, followed by a rinse in hot water containing dichromate salts. The second bath is known as the R.A.E., and deposits a greyish or black film of a complex nature upon the surface of castings after immersion in the boiling solution for approximately 30 minutes; the parts are subsequently rinsed in hot water and allowed to dry.

It is necessary to maintain the

TABLE I.

PROTECTIVE TREATMENTS FOR ELEKTRON CASTINGS.

Type.	*Composition.*	*Procedure.*
Golden Chromate.	15% Potassium Dichromate. 20/25% by Volume conc Nitric Acid. Made up with cold water.	Rapid Dip. Usually not exceeding two minutes owing to excessive solution of metal.
R.A.E. Bath.	3.0% Ammonium Sulphate. 1.5% Ammonium Dichromate. 1.5% Potassium Dichromate. 0.5% Ammonia. In water.	30 minutes immersion in the boiling solution.

R.A.E. bath at a pH of from 5·6—6·7 to achieve best results, and it is important to note that there is a significant difference between the two methods, i.e., the first named will dissolve metal during "dipping" but the R.A.E. method can be applied to fully machined parts, without much risk of dimensional losses. Bushrod[2] has pointed out that the description "protective treatment" is a misnomer, the above baths not giving much protection by themselves, but they do form an excellent base for subsequent paint protection which is very efficient.

Anodic treatments[3] analogous to those applied to aluminium alloys have been persevered with but have not found wide application as yet, probably because they do not offer outstanding improvements; the need for further work on this type of coating is indicated.

X-ray Inspection

During the war this form of inspection played a very important part in the manufacture of magnesium castings by reason of the Air Ministry's system of classification for castings used in aircraft. Castings were placed in classes 1, 2 or 3. Class 1 being the most important and requiring full X-ray inspection on each individual casting; at the discretion of the A.I.D. radiological inspectors, some reduction was given on certain castings if proved to be regularly sound. The magnesium alloys possess a low coefficient of absorption, which means that slight differences of density are only detected under the best conditions, and as the fundamental basis of X-ray inspection is the observance of voids of one sort or another, i.e. density differences, which require best conditions, the method is inevitably expensive for magnesium.

There are two methods of utilising X-rays as an inspection tool (*a*) fluoroscopy or the examination of castings in an X-ray beam which projects a shadow of the casting upon a fluorescent screen and (*b*) radiography, which entails the production of an image on a photographic film and, after ordinary photographic development, subsequent examination of the film under suitable conditions. (See Fig. 1).

As fluoroscopy is only capable of rendering relatively gross flaws it is useless for the purpose of magnesium alloy inspection and radiography must always be used. The casting to be examined is placed upon a film enclosed in an envelope at a given distance from the X-ray tube and in such a position that the particular area to be inspected will record well; after setting up the job (Fig. 2) the operator comes out of the X-ray room, closes the lead lined doors, and makes the shot by operating a switch gear which is in a cubicle located outside the room. This procedure is necessary owing to the harmful effects of X-rays upon the body tissues[4]; in fact, stringent regulations are in force regarding protection from the rays and the walls of the room housing the X-ray set are either lead lined, plastered with or built of a barium-containing brick and the doors are fitted with safety switches which prevent any generation of the X-rays while the doors are ajar. Modifications to this type of X-ray plant were developed with a view to increasing the speed of examination, and designs were based on the fact that the X-ray set must be exposing work while, at the same time, further batches are being prepared, for instance, similar methods to the turntable system incorporated in grit blasting plant.

The fundamental conditions necessary to effect the best results are as follows: (1) use of a film with the finest possible grain size; (2) use of a tube with a fine focal spot; (3) use of from 4 to 5 ft. minimum tube film distance; (4) use of the lowest kilovoltage consistent with adequate penetration of the section; (5) obtaining good film object contact; and (6) correct use of filters.

The defects which can be found by X-ray examination are internal blows, oxide pockets, flux, microporosity and foreign inclusions, but it is the presence of micro-porosity which is most difficult to detect. In this connection it is essential to realise that this method of flaw detection has its limits, especially with regard to complicated castings, and a full understanding of these is necessary to be able to carry out X-ray examinations with confidence[5]; this is best obtained by the use of a device such as a penetrameter used in conjunction with the intelligent application of experience. It is of little use going to the expense and trouble of using X-rays unless the results are justifiable, and it must be emphasised that unless the best conditions are provided for radiography of magnesium alloys the job is a waste of time. In order to increase the efficiency of X-ray inspection all radiographs are scrutinised and reported upon by two separate radiologists. The Americans use X-rays differently, they prefer to make maximum use of the apparatus in the development of a casting technique, but once this is established they check on a small percentage basis.

There is another function of X-rays which, although involving inspection, is entirely separate from the type of inspection outlined above and that is foundry development and control, in which the X-ray laboratory is able to point out the foundryman's troubles at their source. Actually, this is very similar to the American method and will no doubt be widely used by magnesium foundries on castings which justify the expense incurred, in any case, it is not possible to adopt the A.I.D. method on commercial work owing to the cost.

4 W. Birks, M.Sc., F.I.P., "X-ray Protection, Chap. 9. *Handbook of Industrial Radiography.* E. Arnold & Co.

5 W. H. Harper, B.Sc., "The Radiography of Light Metals." *Handbook of Industrial Radiography.* E. Arnold & Co.

Heat Treatment

Theoretical Considerations. — The magnesium end of the system Mg–Al is reproduced in Fig. 3 (after Raynor, Institute of Metals), and this will form the basis for the explanatory matter to follow. Although the normal Elektron alloys strictly belong to a ternery system the amount of zinc is not large enough to radically displace the lines of the binary diagram and, bearing this in mind, the dotted line is inserted to represent the solidification of a typical Elektron alloy. It will be recalled that these alloys do not solidify in the orthodox manner, i.e., solid solution plus eutectics, as shown in the equilibrium diagram, but that the second phase β consists largely of Mg_4Al_3; however, this constituent behaves in the same way as eutectic during heat treatment and any difference can therefore be ignored. On cooling down from the liquid state the α constituent begins to separate out and after the solidus is crossed the alloy consists wholly of α solid solution; with further cooling, however, the aluminium is incapable of being

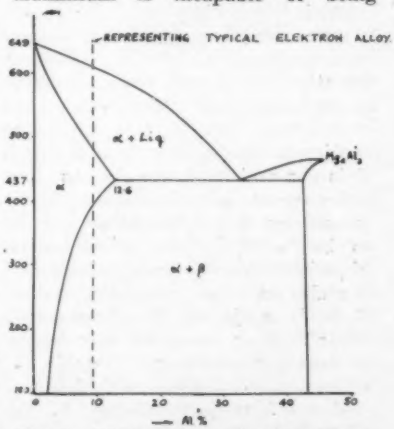


Fig. 3.—Magnesium end of the system Al-Mg. (Raynor, Institute of Metals) Dotted line represents typical Elektron alloy (with reservations, see context).

totally held in solution, and after crossing the sloping solubility curve the second phase β appears, with the result that on reaching room temperature the alloy consists of an α matrix with some β constituent concentrated at the grain boundaries as shown in Fig. 4. The sloping solubility line already referred to gives the clue that the alloys are amenable to heat treatment and solution heat treatment or homo-

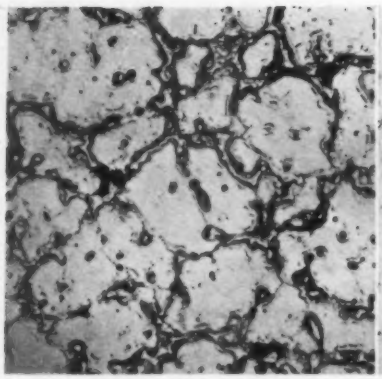


Fig. 4. Elektron AZ91. As Cast. Note prominence of β constituent at grain boundaries.

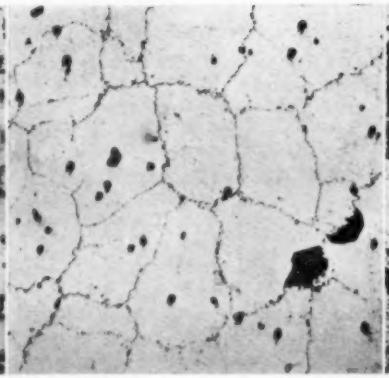


Fig. 5.—Elektron AZ91. Solution Heat Treated. The β phase has been absorbed into the solid solution matrix.

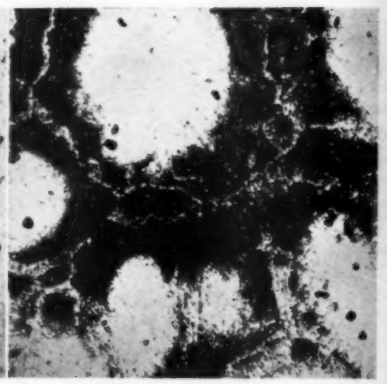


Fig. 6.—Elektron AZ91. Fully Aged. The Mg_4Al_3 has been precipitated as fine particles giving a "keying" action.

genisation is obtained by heating the alloy to a point above the solubility curve, but not exceeding 437° C, and holding for several hours. In this way the β is absorbed into the solid solution matrix and after reasonably rapid air cooling the metal to room temperature it possesses the microstructure shown in Fig. 5; slow cooling tends to produce some precipitation of β with consequent loss of elongation and should be avoided.

It is very important that the temperature during heat treatment does not exceed 437° C or some liquation of β will occur, resulting in typical micro-porosity effects. As a safeguard against this happening heating is usually done in two stages. This absorption of the β phase into a homogeneous solid solution is the reason for the substantial increase to be found in mechanical values. Material which has been homogenised is stable at room temperatures, but, if it is subjected to temperatures of 150° C or more for any length of time, precipitation of fine Mg_4Al_3 will occur, causing loss of ductility.

The effects just referred to are allowed to occur under controlled conditions when the material is required in the fully aged condition and are brought about in the following manner. The alloy, which has received the above solution heat treatment, is heated to a point below the sloping solubility curve (usually 200° C) for some hours and part of the excess β phase, which has been taken into solution, is precipitated as very fine particles on the cleavage planes of the alloy crystals; the microstructure of the material in this condition is shown in Fig. 6. The increase in proof stress and hardness, which is the distinctive feature of the metal in this condition, is explained by the presence of this distributed hard constituent and the material is quite stable, but the low elongation which accompanies the change is disadvantageous.

The simple annealing process is brought about by heating the alloy to a zone below the solubility curve (usually from 250° to 320° C) whereupon particles are precipitated from the super-saturated areas of the matrix with a similar yet minor effect to that obtained above. This process was originally mooted to relieve casting stresses and is very important from this point of view; however co-incident with the stress relief there occurs positive improvement in the strength of the material which requires an explanation; hence the metallurgical description above.

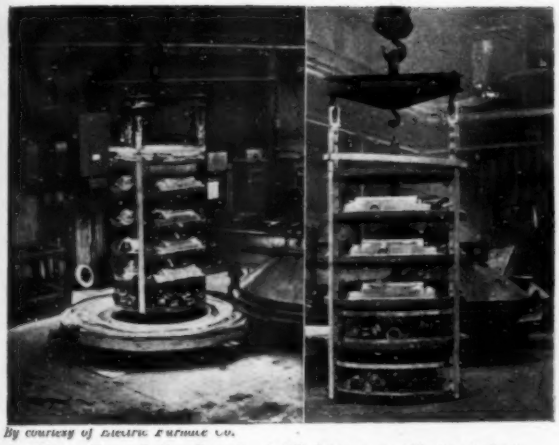
Practical Methods. Solution treatment of magnesium castings is usually carried out in electrically heated pit furnaces with forced air circulation and, owing to the dangers which accompany high temperatures, careful pyrometric control is installed with each furnace. The castings are placed upon machined racks and each load is put in the furnace bodily by overhead crane, which subsequently removes the load after treatment. A tray of iron pyrites is also included with each load, releasing SO_2 throughout the heating period, thus militating against the chances of oxidation and possible burning of the metal. The strength of magnesium alloys at temperatures in the region of 400° C. is very low and great care has to be taken to see that any complicated or overhanging parts of castings are adequately supported to stop any sagging tendencies.

Assuming the furnace to be hot from the previous charge, the load is placed in and the lid closed into its seal of asbestos and sand; the temperature is now allowed to rise to 390° C. and the charge is maintained at this level for about 8 hours. A second rise to approximately 420° C. now follows for the remainder of the 24 hours after which the furnace is opened, the load removed, and the cycle repeated. (See Figs. 7 and 8).

To facilitate operations, when pressure of work is acute, extra racks are brought into use which when previously loaded up with castings form the next charge; upon expiration of heat treatment re-charging the furnace is rapidly accomplished by simple substitution of the racks.

Rectangular electric muffles placed at floor level are also used for this work and usually embody a horizontal mechanical charging device, for the placing in or removal of complete racks of castings; in fact the process used with these muffles is identical to the one just described, but particular care must be taken to see that the door is efficiently sealed. It is sometimes the practice to have a shallow bed of gravel to bed the castings in the place of the machined racks but the principle is the same, that is, to prevent distortion of the work which is mechanically weak at the high temperatures involved.

For either the low temperature, stress relief, anneal or age hardening treatment of castings, no elaborate apparatus is required and gas fired batch ovens similar to those used as core ovens are frequently used; however, they are thermostatically controlled to ensure accuracy because the same risks are present and should the temperature bolt for any reason the results would be serious. This type of oven is reasonably cheap and new ovens easily installed as output



By courtesy of Electric Furnace Co.

Figs. 7 and 8.—Load of Elektron castings being removed from electric pit furnace after heat treatment.

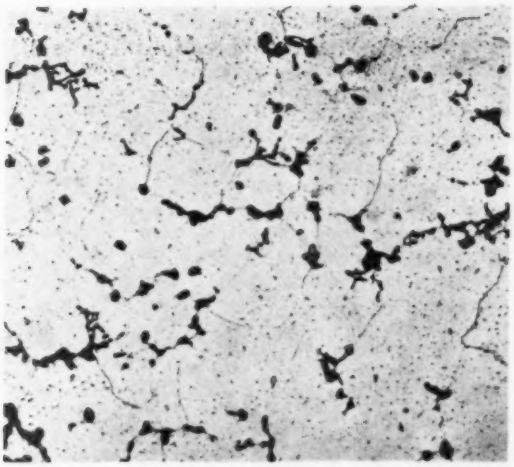


Fig. 9.—The typical appearance of micro-porosity under the microscope, voids of a "dog's hind leg" character.

increases, for this reason charging apparatus is rarely used, large castings being placed in singly and smaller work contained in wire baskets. In the relief anneal process the temperature of the oven is raised to 250° C for a period of 4 hours after which it is opened and allowed to cool; slightly higher temperatures and times up to 8 hours are preferred by some, but the metallurgical results are more or less the same.

The age hardening precipitation which follows solution heat treatment is obtained by raising the temperature of the stove to 200° C. and maintaining for 10–12 hours; natural air cooling follows when the stove is opened.

There is no reason why the electric furnaces or muffles used for the solution heat treatment should not be used for low temperature work, in fact, they sometimes are; it is merely a question of doing the job economically with the apparatus available.

Test bars are included in each load and when pulled give a very good idea of the efficiency of the respective treatments; micro-structures taken from such test bars do not give much additional information, the best method is to try to obtain a micro-section from one of the larger castings; this is fairly simple as there is usually a small amount of excess metal on a rough fettled casting.

The most important consideration when heat treating magnesium is to see that all controls and pyrometric equipment is accurately and regularly checked, especially with regard to the solution heat treatment procedure; it must be remembered that these furnaces operate at the most dangerous temperatures and on a 24 hour cycle; sometimes they operate continuously for weeks on end with the lid open only about 10 minutes daily while the racks are changed.

Defects of Magnesium Sand Castings

Reflection upon the chemical activity of magnesium alloys will bring comfort to the machinist and ultimate user of magnesium castings, because it will be realised that due to this vigourous activation the majority of usual casting defects will have been trapped before the casting is despatched. It can be clearly stated at the outset that faults such as blowholes and dross or scum will rarely be found beneath the skin upon machining and the value of this cannot be discounted.

Micro-porosity. This defect, once much advertised as "micro shrinkage," is apt to occur in most magnesium castings; sometimes by virtue of its position and small amount its effect is quite insignificant, but in other cases its presence is of a serious nature. The term "micro-shrinkage" has been generally abandoned because research work has proved that other factors, such as gassy metal, moulding sand reactions, besides lack of feeding, can be responsible for the conditions; probably the most vital contribution to the problem in the country has been made by W. A. Baker and his investigations are worthy of some study.[6] Since Baker's work many investigators,[7] [8] [9] [10] particularly in America, have studied the phenomena, especially from the point of view of gas content and the view is now held that, from whatever cause the effect is produced, the micro-structure or radiographic appearance is the same. A typical micro-structure is shown in Fig. 9 and it will be observed that micro-porosity consists of voids or angular discontinuities which exist usually in patches or colonies; the individual cavities cannot be discerned by the naked eye so the defect is simply known as "porosity which is observed with a microscope," i.e., micro-porosity. These individual voids are located at the grain boundaries and their formation is best imagined by reference to the Mg_4Al_3 in the as-cast structure (Fig. 4): substitute, drain away or otherwise remove the Mg_4Al_3 and the void remains—this is how the defect is caused when the principles for its avoidance (outlined below) are disregarded. Uncontrolled heat treatment can also produce this effect and identical micro-porosity appearances can arise in this fashion. To qualify and therefore render accurate the above brief attempt at an explanation of the phenomena is unnecessary here, and radiographs are not shown because they do not reproduce well, but, when parts are radiographed, micro-porosity appears as streaks or feather-like dark patches against the uniform background.

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6 W. A. Baker, B.Sc., "Microporosity in magnesium castings." *J. Inst. Metals.* Serial No. 989.

7 F. A. Fox, M.Sc., "The properties of some magnesium aluminium zinc casting alloys and the incidence of micro-porosity." *J. Inst. Metals.* Serial No. 999.

8 J. DeHaven, J. A. Davies, L. W. Eastwood, "Reduction of micro-porosity in magnesium Alloy castings." *American Foundryman*, June, 1945.

9 R. S. Busk, R. F. Marande and W. C. Newhams, "Effect of gas on the properties of magnesium sand casting alloys." *American Foundryman*, May, 1945.

10 R. S. Busk and C. G. Bobalek, "Hydrogen in magnesium alloys." *Metals Technology*, October, 1946.

An interesting point arises here regarding the relative difference in sensitivity between a radiograph of an as-cast structure and that of a solution heat treated structure; as the single plane radiographic film is the result of a projection of several planes of a casting, a given patch of micro-porosity will be partly obscured by the richer constituent Mg_4Al_3 existing between the grains in the as-cast structure, solution heat treated castings in which there is no Mg_4Al_3 would therefore possess greater potential fault detection upon radiographic examination.

Upon fracturing a casting after heat treatment any micro-porosity is revealed as discolourations ranging from light straw to black, the deepening of colour denoting increased severity of attack; this form of inspection, unfortunately destructive, is an excellent way of tracking down troubles and is practised by some firms who decide to fracture a percentage of the output of a given casting.

Each type of casting should be considered separately when means for the elimination or reduction of micro-porosity are discussed, but the following principles (some of which have been mentioned in an earlier article) must be applied to succeed at all. (1) Use of metal and melts substantially free from gas; (2) use of a correct running system; (3), proper use of chills; (4) adequate feeding conditions; (5) good venting; so that steep directional solidification is assured and also that solidification is rapid.

The guaranteed elimination of micro-porosity from any one type of casting is a painstaking and possibly expensive business and a slight amount is likely to be present in the majority of commercial castings; a brief review of its effects therefore, is worth examining. Its influence on mechanical properties is severe, even small amounts lowering the ultimate tensile strength by 25 per cent. or more, yet little deterioration is shown in the 0.1 per cent. proof stress values: however, reliance on this latter evidence is fraught with danger as there seems little doubt that the fatigue properties of the material would be very adversely affected, corrosion resistance would be lowered should the defect outcrop to the surface.

This somewhat gloomy picture is not so bad as one would suppose for it is extraordinary the amount of micro-porosity a well-designed casting can put up with. The question of design then emerges once again and the care and forethought necessary and early discussion on design with the foundry technicians cannot be stressed too highly. Examination of castings taken from German aircraft have sometimes revealed amounts of micro-porosity which would apall the English foundry manager and metallurgist, but by virtue of good design the casting has not failed. It is a curious feature of the German magnesium industry that they regard micro-porosity simply as a foundry problem and as no concern of the metallurgist; this view is not held here.

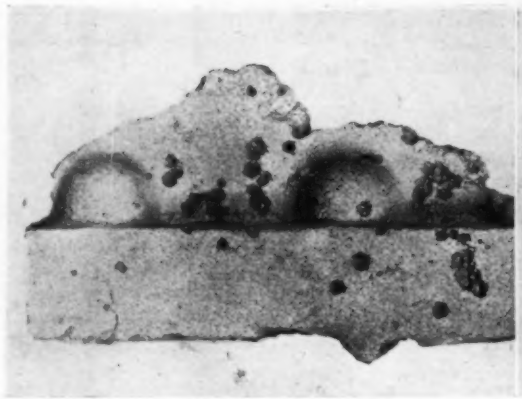

Fig. 10.—Ragged cavities produced by oxidation or burning of the metal.

Fig. 11.—Results of incipient fusion of eutectic during solution heat treatment.

Flux inclusions. In the early days of magnesium sand castings manufacture this trouble occurred all too frequently but with the development of new fluxes and proper methods of using them it became almost non-existent. Any particles of flux which do lodge in a casting give rise to rapid attack and white excrescences of corrosion products soon begin to build up where the flux has outcropped; a freshly machined face will betray the existence of flux inclusions extremely rapidly.

Oxidation. When the inhibitor in the moulding and/or core sands has not functioned efficiently, oxidation or actual burning of the metal occurs and results in ragged and sometimes deep cavities which are filled with grey powdered oxide (see Fig. 10) until grit blasted clean. A variety or combination of circumstances causes the trouble, but the fundamental consideration is that the inhibitors have been temporarily overcome by the air or moisture which has then attacked the pasty mass of cooling metal. Prevention of the trouble consists of maintaining the correct amounts of inhibitor in the sands, keeping the moisture low, attending to core stove temperatures and using sand with adequate permeability.

Scum. This is the term applied to any entrapped oxide or nitride skins which lodge in or on the surface of the casting, such skins are the results of improper metal preparation, bad running and gating practice, and excessive moisture of the sand in the sprue and runner areas. By causing a mechanical break in the continuity of the structure of the material they lower the mechanical properties but do not contribute to any corrosion tendencies.

Misruns. This common foundry trouble requires special mention with regard to magnesium castings owing to the ease of oxide formation on the metal streams; such oxide will render more difficult the joining up of these streams with resultant misruns. The formation of oxide is favoured with increasing temperature and therefore it will be seen that a high pouring temperature can be and actually is a cause of this trouble.

Magnesium foundry personnel are no strangers to blows, sinks, draws, and the other usual defects common to the production of castings in most metals, but one other defect which magnesium castings are liable to incur is incipient burning during heat treatment. This is caused by local overheating resulting in the melting of the eutectiferous material which sometimes oxidises into tiny volcanoes as shown in Fig. 11.

Cold-Working and Recrystallisation of 70-30 Cartridge Brass

By Charles A. Nagler and Ralph L. Dowdell*

Much work has been published on the effect of cold work and recrystallisation of 70–30 cartridge brass. This work was undertaken partly to confirm the phenomena published, but more especially to find the effects of more drastic cold working on recrystallisation.

THE alloy for this research was taken from a cast cake of brass, 5 in. in thickness having the following analysis :—

Copper	68·17
Lead	Trace
Iron	0·018
Tin	Nil
Zinc	Balance

Hardness determinations carried out on the cast cake revealed an average Rockwell " B " hardness of 40. From the cake of brass, ten strips approximately ½ in. thick, 1 in. wide, and 5 in. long, were cut and given an average 10% reduction by cold rolling. In Table I is given the dimensional data stating the average thickness of the original strips as cut, thickness after rolling, and rolled reductions in both inches and percent. The effect of cold rolling the cast brass was to increase the average Rockwell " B " hardness of the strips from 40–49. After the 10% deformation, the ten brass strips were annealed at 1,472° F. (800° C.) for 20 minutes and furnace cooled in 24 hours to room temperature. This anneal produced an average grain size in the bars of 0·135 mm. with a Rockwell " B " of 36. Fig. 1 shows the average grain size produced in the brass on the anneal. The grains are equiaxed and show twin bands which is indicative of a metal of the solid solution type which has been cold worked and recrystallised. There is no evidence of a cast-cored structure in Fig. 1 that was present in the brass cake before rolling and annealing.

TABLE I.—Rolling Log of Cast Brass Samples Prior to Annealing.

70–30 Cartridge Sample Bar No.	Average Thickness Before Rolling in Inches	Average Thickness After Rolling in Inches	Rolled Reduction in Inches	% Deformation
1	0·470	0·430	0·040	8·53
2	0·474	0·430	0·044	9·30
3	0·474	0·430	0·044	9·30
4	0·478	0·430	0·048	10·05
5	0·494	0·430	0·064	12·98
6	0·477	0·430	0·047	9·86
7	0·478	0·430	0·048	10·05
8	0·4785	0·430	0·0485	10·04
9	0·4820	0·430	0·052	10·80

Table II shows data covering the rolling of the 70–30 cartridge brass to deformations of 10, 20, 30, 40, 50, 60, 70, 80 and 90%, respectively. The thicknesses are given of the strips in inches prior to rolling and after rolling to the desired percent. of deformation, the deformation in inches and percent., the number of passes used in obtaining the desired cold deformation, and the resulting Rockwell " B " hardness. Table III is the rolling log, indicating the thickness in inches produced on each pass. The rolling of the brass was carried out on a set of 5-in. rolls, a slight tension being put on each strip during rolling to maintain straightness. In rolling, an attempt was made to nip the bars square on the rolls so as to produce an increase in length with no material change in the width of the strips. After a 10% deformation was reached in rolling, a series of small cracks was evident on the edges of the strips. There were no difficulties encountered in rolling the brass up to 90% reduction. The cracks on the rolled surface became more pronounced as the percent. of reduction increased, but not to such a degree as to cause failure of the strips during cold reduction.

TABLE II.—Rolling Data

Sample Number	Average Thickness Before Rolling in Inches	Average Thickness After Rolling in Inches	Rolled Thickness Reduction in Inches	% Thickness Reduction	Number of Passes	Rockwell " B " Hardness
1–D ..	0·430	0·390	0·040	9·30	3	55
2–D ..	0·430	0·348	0·082	19·08	6	75
3–D ..	0·430	0·301	0·129	30·0	10	82
4–D ..	0·430	0·260	0·170	39·0	12	87
5–D ..	0·430	0·215	0·215	50·0	15	91
6–D ..	0·430	0·172	0·258	60·0	18	94
7–D ..	0·430	0·129	0·301	70·0	21	96
8–D ..	0·430	0·086	0·344	80·0	24	98
9–D ..	0·430	0·043	0·387	90·0	27	99

TABLE III.—Rolling Log.

Pass	Thickness in Inches	Pass	Thickness in Inches
0..	0·430	15	0·215
1..	0·417	16	0·200
2..	0·403	17	0·185
3..	0·390	18	0·172
4..	0·376	19	0·155
5..	0·362	20	0·141
6..	0·348	21	0·129
7..	0·335	22	0·113
8..	0·320	23	0·098
9..	0·306	24	0·086
10..	0·301	25	0·069
11..	0·274	26	0·054
12..	0·260	27	0·043
13..	0·245	—	—
14..	0·229	—	—

After the strips of 70–30 cartridge brass had been rolled to reductions of 10, 20, 30, 40, 50, 60, 70, 80 and 90%, respectively, samples were cut for microscopic and hardness tests. Fig. 2 is a graph showing the relationship between cold reduction on rolling and Rockwell " B " hardness. Microscopic observations revealed that for the first 30% of cold deformation on rolling, the worked effect is limited to the surface of the strip. In Fig. 3 is shown the condition noted on the surface of the brass sample which has been given a cold deformation of 20%. The grains show slight evidence of deformation

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Fig. 1.—The average grain size of 0·135 mm. produced in the 70-30 cartridge brass strips given a 10% deformation and annealed at 800° C. (1,472° F.) for 20 min. and furnaces cooled in 24 hrs. to room temperature. X75

Fig. 3.–The condition noted on the surface of the brass sample which had been given a 20% deformation. The grains show slight evidence of deformation with some deformation of the straight twin bands and the presence of few slip bands. X75

Fig. 4.–The condition noted near the edge of the brass sample which had been given a 50% deformation. The grains have been elongated in the direction of rolling, the individual grain boundaries being readily evident. X75

Fig. 5.–The condition noted in the brass sample which has been given an 80% deformation. The grains are elongated in the direction of the rolling and are compressed. Numerous slip bands are present on the deformed grains. X75

with some distortion of the straight twin bands and the presence of few slip bands. In the samples with deformations of 40, 50, and 60%, respectively, slip bands were evident, and the grains still showed remnants of the twin bands. In Fig. 4 is shown the condition noted near the edge of the brass sample which had been given a cold deformation of 50%. The grains show evidence of much cold deformation which appeared as numerous wavy slip bands. The grains show evidence of being elongated in the direction of rolling and the individual grain boundaries are readily evident.

The cold rolling of 70, 80 and 90% produced severe deformation in the brass. In Fig. 5 is shown the condition in the brass sample which had been given a cold reduction of 80%. The grains have been elongated in the direction of rolling and are compressed. Numerous slip bands are present on the deformed grains. The grains are distorted and individual grains and grain boundaries can not be recognised.

The observations on the effect of cold working of the 70–30 cartridge brass after an anneal of 1,472° F. (800° C.) for twenty minutes made by Mathewson and Phillips[1] are in good agreement with those previously described.

Referring to the work of R. S. French[2] on grain growth and recrystallisation of 70–30 cartridge brass in Fig. 5 of their paper the Rockwell " B " hardness is plotted versus percent reduction by rolling. The brass used was annealed to 0·053 mm. grain size before rolling. The hardness on the Rockwell " B " scale produced by cold rolling in the work of French is in good agreement with the hardness produced on rolling as shown in Fig. 2.

To study the effect of annealing on the grain structure and hardness of the 70–30 cartridge brass, samples which had been given various percents of deformation were annealed for 1 hour at temperatures of 400°, 500°, 600°, 700°, 800°, 900°, 1,000°, 1,100°, 1,200°, 1,300° and 1,400° F., respectively. After each of the various anneals, the samples were checked for Rockwell " B " hardness and grain structure. In Table IV is tabulated

TABLE IV.

Annealing Temperature ° F.	Rockwell " B "* Hardness after anneal which followed cold reductions of								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
400	51	73	83	88	93	96	98	99	99
500	50	72	83	89	93	96	98	96	89
600	49	71	81	80	70	61	67	72	59
700	47	58	47	44	50	53	57	58	47
800	38	34	37	39	42	44	47	44	35
900	28	32	34	34	34	35	37	36	30
1,000	27	31	31	31	31	32	29	28	26
1,100	26	29	29	29	28	28	26	21	24
1,200	25	27	26	26	24	25	23	20	22
1,300	25	25	24	24	21	23	21	19	20
1,400	24	23	22	22	18	18	18	17	18

* The Rockwell " B " hardness readings tabulated for each anneal are an average of three readings taken on a diagonal on the one-half by one inch face of the sample.

the average hardness produced in each of the sample brasses after the various anneals, the hardness being determined in all cases on one of the flat-rolled surfaces of the specimen. Three hardness determinations were carried out on a diagonal drawn on the $\frac{1}{2} \times 1$ in. face

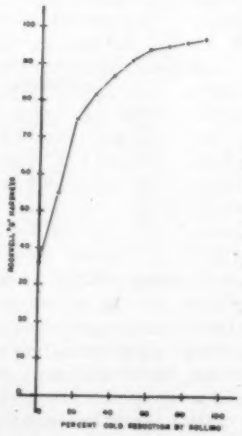


Fig. 2.—Effect of cold rolling on the hardness of 70-30 cartridge brass.

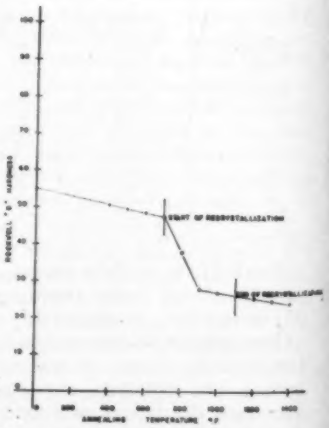


Fig. 6.—Annealing curve for a 70-30 cartridge brass after a 10% cold reduction.

1 Mathewson, C. H. and Phillips, A. Recrystallisation of Cold-worked Alpha Brass and Annealing. Trans. A.I.M.M.E. Vol. 64 (1916), pp. 608–770.

2 French, R. S. Grain Growth and Recrystallisation of 70–30 Cartridge Brass. Metals Technology. February, 1944 T.P., 1,673, Vol. 11, No. 2.

Fig. 7.—Grain structure present in the 70-30 brass which had been given a 10% deformation and partially recrystallised. The sample was lightly etched to show the small recrystallised grains. X75

Fig. 8.—Recrystallised grain size of 0·90 mm. produced in the 70-30 brass which had been given a 10% deformation and annealed at 594° C. (1,100° F.) for 1 hour. X75

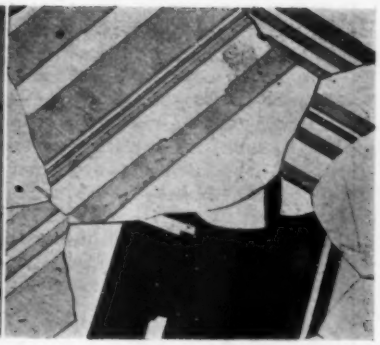


Fig. 9.—Recrystallised grain size of 0·250 mm. produced in the 70-30 brass which had been given a 10% deformation and annealed at 760° C. (1,400° F.) for 1 hour. X75

of the sample, the positions being equidistant apart for the length of the diagonal. The maximum hardness variations for any sample at the three positions on the diagonal were three points on the Rockwell " B " scale Prior to the hardness determinations, the surface of the specimens was polished lightly on No. 1 polishing paper.

In Fig. 6 is illustrated the annealing curve for a 70–30 cartridge brass after a 10% cold deformation. There is a slight decrease in hardness in annealing over the temperature range of 400°–700° F. Microscopic studies of samples annealed at temperatures below 700° F. revealed no recrystallised areas. The grain structure showed the presence of a few slip bands caused by the slight cold rolling of 10%. There is a marked decrease in hardness from 700°–1,100° F. in Fig. 6 caused by recrystallisation. The recrystallisation caused the strained metal to revert to a condition relatively free of strain. In Fig. 7 is illustrated the grain structure in the brass which had been given a 10% deformation and partially recrystallised when examined at 75 magnifications. The large grains do not show any slip bands, the reason being that the sample was etched rather lightly to show the small recrystallised grains. Tests on the sample in deep etching with 50% ammonia hydroxide and 1½% hydrogen peroxide revealed the presence of slip bands in the large grains—but etched the small recrystallised grains to a degree where they could not be recognised. Annealing at the temperature of 1,100° F, produced a recrystallised grain size as shown in Fig. 8. Comparing Fig. 1, the starting grain size and Fig. 8, the grain size after recrystallisation the effect of the 10% cold deformation and anneal for 1 hour at 1,100° F. is evident and resulted in some grain refinement. The average grain size reduced from 0·135 mm. to 0·090 mm. Further annealing of the 10% cold deformed 70–30 brass beyond the temperature of recrystallisation resulted in grain growth taking place as is shown in Fig. 9. In Fig. 10 is illustrated the annealing curve for a 70–30 cartridge brass which had been

TABLE V.

TABLE SHOWING THE RELATIONSHIP BETWEEN COLD DEFORMATION AND ANNEALING TEMPERATURE FOR START AND END OF RECRYSTALLISATION.

% Cold Deformation	Temperature in ° F. for start of Recrystallisation	Temperature in ° F. for end of Recrystallisation
10	700	1,100
20	650	1,000
30	600	900
40	580	850
50	550	800
60	520	750
70	500	700
80	480	600
90	470	580

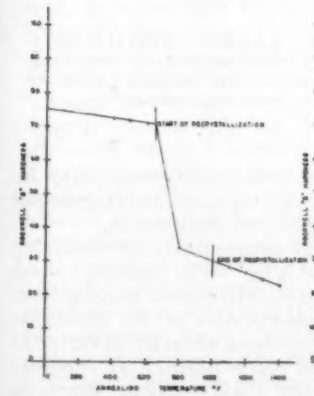


Fig. 10.—Annealing curve after a 20% cold reduction.

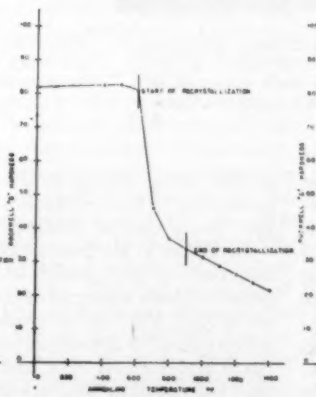


Fig. 11.—Annealing curve after a 30% cold reduction.

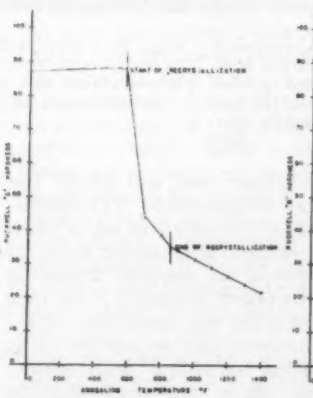


Fig. 12.—Annealing curve after a 40% cold reduction.

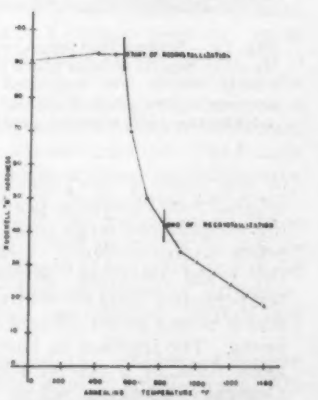


Fig. 13.—Annealing curve after a 50% cold reduction.

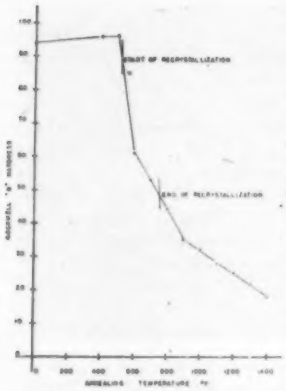


Fig. 14.—Annealing curve after a 60% cold reduction.

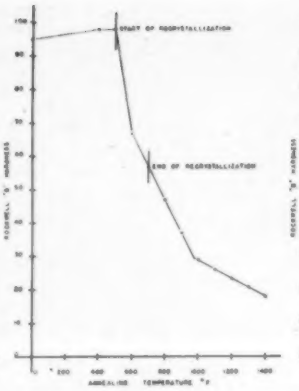


Fig. 15.—Annealing curve after a 70% cold reduction.

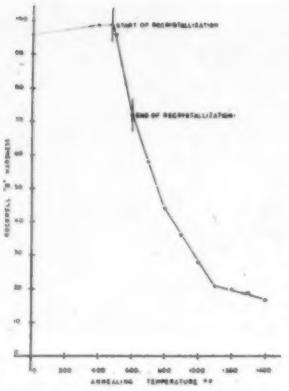


Fig. 16.—Annealing curve after a 80% cold reduction.

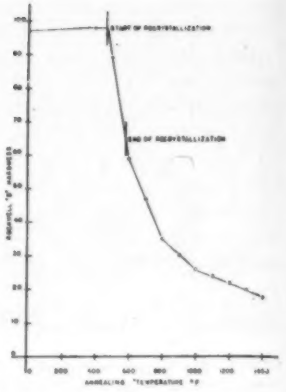


Fig. 17.—Annealing curve after a 90% cold reduction.

given a 20% deformation. This curve is similar in shape to that of Fig. 6. Microscopic examination and hardness tests carried out on the variously annealed samples revealed that the temperature for start of recrystallisation with a 20% cold reduction starts at 650° F. and ends at 1,100° F. The microstructures observed were similar to those shown in Fig. 8, 9 and 10 for a 70–30 brass with 10% deformation and annealed at various temperatures up to 1,400° F.

Figs. 11, 12, 13, 14, 15, 16 and 17 illustrate the annealing curve for 70–30 cartridge brass after 30, 40, 50, 60, 70, 80 and 90% deformations, respectively. In the aforementioned figures there is an increase in hardness prior to the start of recrystallisation over and above the original rolled hardness prior to annealing. The annealing temperature range prior to recrystallisation is often referred to as recovery. Complete microscopic study of the grain structure produced at various annealing temperatures on the cold-worked brasses up to that which causes recrystallisation did not reveal any differences. The increase in hardness may be attributed to some form of a precipitation hardening phenomenon. Generally speaking alloys which are susceptible to precipitation hardening will illustrate that phenomenon most readily when the metal is given a marked cold reduction prior to annealing. The critical amount of stress and the proper annealing temperature may cause the age hardening to take place readily. This is a very good problem for a detailed investigation.

Soon after the maximum hardness is reached during the recovery period on annealing, the metal starts to soften with recrystallisation taking place. When the metal starts to recrystallise the new, small, stress-free equiaxed grains will appear at the grain boundaries and within the cold-worked grains also, Fig. 18. There is a tendency at the earliest stage of recrystallisation for the small grain to appear in greater number at the grain boundaries—then within the grain. There tends to be a greater stress set up at the grain interface and also the possibility of fragmentation taking place, the fragmented particles acting as centres for recrystallisation.

In Table V are listed the temperatures for beginning and end of recrystallisation for 70–30 cartridge brass given various amounts of cold deformation ranging from 10–90%. Fig. 19 is representative of the fine-grain structure at 75 diameters produced when 70–30 cartridge brass is deformed 70% and recrystallised. To correlate the information concerning cold working, annealing temperatures, and Rockwell " B " hardness a model was drawn showing these relationships as is shown in Fig. 20.

Fig. 18.—Shows that when recrystallisation begins to take place the new, small, stress free euqiaxed grains appear at the grain boundaries and within the cold worked grains also. X75

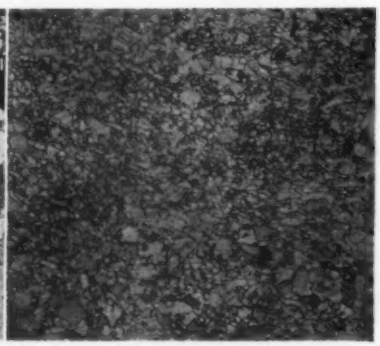


Fig. 19.—Recrystallised grain size of 0·015 mm. produced in the 70-30 brass which had been given a 70% deformation and recrystallised. X75

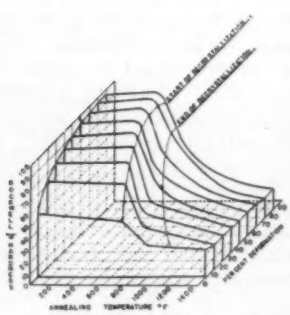


Fig. 20.—Showing relationship between cold reduction, annealing temperature, and hardnes s of 70-30 cartridge brass.

From the model the following conclusions can be drawn.

(*a*) On fully annealed samples of 70–30 cartridge brass as the per cent. of deformation by cold working is increased, the hardness of the brass will increase. The greatest change in hardness takes place for the first 60% of deformation.

(*b*) Cartridge brass which has been given deformation in excess of 30% will increase in hardness during the recovery period on annealing prior to softening where recrystallisation takes place.

(*c*) As the per cent. of deformation in 70–30 cartridge brass is increased the temperature for the start and end of recrystallisation is lowered.

(*d*) The lower the percentage of cold reduction prior to annealing, the larger will be the resulting grain size as shown in the sequence of Figs. 1, 3, 7 and 18, the mild strain gradient causing germanation.

(*e*) The larger the percentage of cold reduction prior to annealing, the smaller will be the resulting grain size. These latter conclusions are in accord with past researches on the effect of strain gradients on grain growth.

The Failure of Metals by Fatigue

A symposium, in five sessions, on the failure of metals by fatigue, was recently held under the auspices of the Faculty of Engineering, University of Melbourne, Australia, at which some thirty papers were presented for discussion. The symposium is comprehensive in its presentation of the subject, and brief abstracts of some of the papers are given.

AT an early stage in the accelerated use of metals for engineering structures, testing machines were constructed to determine the "strength" of the materials used. It was found, as Professor J. Neill Greenwood pointed out in his general introduction to the subject, that up to a certain more or less well-defined stress for a given metal, there was a proportionality between the applied stress and the deformation produced. The tensile test became the standard means of reference for the engineering designer. It was assumed that :—

(*a*) Stresses lower than the limit of proportionality would be without effect on the metal.

(*b*) Repetition of such stresses would introduce no new feature from the point of view of strength.

(*c*) The stresses concerned were those caused by applied loads, calculated from the total cross section of the part concerned.

Experience soon showed that all three of these assumptions were untenable. There then grew up a practice of designing with a "factor of safety" or rather of increasing the margin of safety, as experience showed that average operating stresses should be much lower than those needed to cause failure in a static tensile test. It so happens, for reasons not yet explained, that there is a fairly definite relationship between the maximum stress which a material will withstand under repeated loading (stress concentration absent) and the "tensile strength" as normally determined. Consequently even to this day, when our knowledge of the effects of repeated stressing has increased enormously, the tensile test rather than an endurance test, forms the basis of specifications even for aircraft material. In the absence of notches, and provided the tensile strength is not greater than about 80 tons/sq. in., ferrous metals will withstand indefinitely cycles of stress in the range of ± 50% of the tensile strength. The highest value of stress which a metal will thus withstand indefinitely is the endurance limit. Non-ferrous metals, and ferrous metals under corroding conditions show no such safe limit, and it becomes necessary to describe the behaviour under such circumstances as a life or endurance of a specific number of cycles of a given range of stress.

Features of Fatigue Failure

Fatigue failures of metals have certain well defined characteristics. In the first place the failure occurs with little deformation even though a tensile test taken from the failed part will show good ductility. Secondly, the fracture itself frequently shows two (sometimes three) distinct zones. Careful inspection of such a fracture will generally reveal the cause of the failure. There is a smooth part frequently showing concentric markings starting from a nucleus or stress raiser, and a rougher part frequently showing bright crystalline facets. This latter feature, being associated in the minds of engineers with brittle material has frequently been considered the cause of failure, the material being said to have "crystallised." We now know that all metals are composed of crystals, and we are directed to the smooth striated part as the cause of the failure. It is this progressive fracture which, spreading through the cross section at a rate determined by the number and magnitude of the stress cycles (not by the time rate of application) has ultimately weakened the component so that it fails suddenly under the normal stressing caused by operational loads. Examination of the fracture will show that the focal spot of the stress markings is a location where the "notch effect" has caused a local concentration of stress. It may have been a pop mark used by a machinist to define a keyway position ; or an inspection or other identification stamp mark ; or a blowhole or slag inclusion in a weld. Sometimes the progressive fracture will have started from the surface of the component ; in other cases the nucleus is internal such as "flakes" in rail heads and forgings. The fatigue crack may develop very quickly or over a period of years, depending on the properties of the material, the magnitude of the local stress and the frequency of stress fluctuations. Consequently under operating conditions slight rubbing of the two surfaces of the crack may occur accompanied by discolouration by grease or oxidation, particularly when lengthy periods of service are concerned.

In the absence of corrosion the number of fatigue cracks in any one locality is very small—frequently there being only one. When operating conditions involve corrosive action as well as fluctuating stress there are many such fatigue cracks, because they start from

microscopic corrosion pits as stress concentrators. It should be realised that the corrosive action may be very mild—even tap water being sufficiently active, and that ordinary evidence of corrosion such as rusting may be absent (as in the failure of stainless steel by corrosion fatigue). "Fretting" or the slight movement between parts of a press fit accompanied by oxidation of the abraded material is an indication of corrosion and leads to multiple fatigue cracks.

METALLOGRAPHY, FATIGUE OF METALS AND CONVENTIONAL STRESS ANALYSIS

By Prof. H. G. Moore.

IN this is outlined the history of stress analysis in pre-metallographic days, in which mention is made of the work of Hooke and the development of elastic theory. Failure of parts designed on this basis led Wöhler to his experimental investigation of the effects of repeated stresses. The use of the microscope by Ewing, Rosenhain and Humphrey revealed the slip nature of mechanical deformation in the crystals of which metals are built up. The microscope further revealed that "fatigue" is a spreading crack, starting at some spot where the localised stresses are higher than the average. Consideration is given to the influence of stress concentration and the sensitivity of materials to notches, and the author points out some of the ways in which such effects can be minimised. In conclusion he warns engineers on the limitations of stress analysis, stating that one of the most dangerous habits which the designing engineer can form is the habit of formula worship. Formulæ for stress, strain and strain energies are to be used, but always within limitations.

Obvious limitations of the ordinary formulæ of stress analysis, and even of the elaborate analyses of the mathematical theory of elasticity, are the fact that their fundamental assumptions of homogeneity, isotropy are not rigidly true for actual structural materials, and that Hooke's law, even within what is assumed to be the elastic range of stress for a material, is probably a very close approximation rather than an absolutely true statement. On the other hand the assumption that structural damage follows when a stress beyond the elastic range occurs over any area of a structural member, *no matter how small that area*, is not necessarily true under static loading, and probably not under repeated loading. If it were true, probably in any building structural damage would have to be recognised at the edges of hundreds of rivets, and in practically all shafts with sharp-cornered keyways structural damage would have to be recognised at the re-entrant corners of the keyway. As a fact, localised yielding in metal structures and machines frequently serves the useful purpose of distributing stress more evenly and cutting down the high peaks of stress-concentration.

When facing design problems involving repeated stress this favourable action of localised yielding must be watched much more carefully than in cases of static loading. Localised yielding may serve to cause a beneficial lowering of stress concentration on the first application of load, but may cause a fatigue crack to start at the hundredth or the thousandth, or the millionth repetition of the loading, especially if the loading is accompanied by rubbing wear. And when a fatigue crack starts, its narrow end is a very bad stress raiser which, if the crack becomes long enough to be seen by a low power magnifying glass, will nearly always spread until serious structural damage is done, frequently complete fracture. Furthermore, a crack once started grows at an accelerated rate, and the number of cycles of stress between the detection of the crack and the final fracture may be only a few thousand.

However, with all their limitations our present-day methods of stress analysis are of a high degree of reliability if used with a careful attention to those limitations. For static structures, and structures or machine parts subjected to not more than a few hundred cycles of stress, the "statistical" truth of our formulæ may be accepted as justifying their use and of neglecting localised stresses at notches, holes, screw threads, keyways and sharp fillets in the case of reasonably ductile metals, *but not in cast iron or* other metals of equally low ductility. In parts subjected to thousands or millions of cycles of repeated stress it is unsafe to neglect any stress raiser. Mathematical or graphical theoretical solutions for stress concentration have been worked out for holes in plates under tension and in shafts under torsion, for notches with known radii at their roots. Some data is available as to actual strength reduction of fatigue strength of shafts with keyways, and considerable photoelastic data is available concerning stresses at fillets in shafts. The theoretical stress-concentration factor may be used as the factor of actual strength reduction, and the results will be on the safe side.

A serious limitation of the use of the common formulæ for stress—the formulæ commonly given in hand books and taught to undergraduate students in strength of materials—is the limited field of loading conditions and shape conditions to which they apply. For example, the common torsion formula applies only to shafts with circular or hollow-circular cross-section. The designer familiar with the common formulæ for stress must be constantly on the lookout for their limitations as to applicability to the shape he is designing and to the magnitudes and directions of the forces and moments acting on it. He must be ready to seek special formulæ or experimental results to aid him in cases where the common formulæ fail.

The strength of materials is not predicted with absolute accuracy by the formulæ for stress and strain in common use, nor even by the elaborate analyses of the most advanced mathematical theory of elasticity. However, if these formulæ and methods of stress analysis are used carefully, with recognition of their limitations, the results even for members under repeated stress may be reliable to a high degree, and the probability of failure low.

Perhaps the most compelling reason to use our common methods of strength computing is that we have no others which are workable. We may recognise the complexity of the real stresses within and between crystalline grains of a metal, but no one yet has even suggested a method for their computation. Perhaps in this matter the metallurgist or the engineer is following a principle which may be his contribution to man's ways of thought.

THEORIES OF THE MECHANISM OF FATIGUE FAILURE

By W. Boas

THE author discusses the development of ideas on the mechanism of fatigue failure, and lays emphasis on the experimental results on which any theory has to be based. Experiments carried out during the last twenty years on metallic single crystals and those using

X-ray diffraction methods have changed the aspect of the problem. Failure by fatigue is merely a special case of failure under all forms of stressing actions and not a special problem of its own, and it must be considered as a consequence of slip. The deformation is localised in the immediate neighbourhood of the fatigue fracture, where it reaches a critical amount. It is the total strain which has a certain characteristic value at fra cture.

In his conclusion, the author describes some of the recent theories of the mechanism of fatigue failure, citing Dehlinger, who emphasised the importance of inhomogeneity of the deformation. This inhomogeneity may be caused by the type of stress applied ; some bending may be produced even in single crystals. It always occurs in polycrystalline materials even if they are subjected to homogeneous uni-axial stresses because neighbouring crystals of different orientation first have different elastic limits and strain-hardening characteristics, and, secondly, are deformed differently in the neighbourhood of the common boundary. The more these internal stresses increase the greater will be the force to be applied externally in order to produce further deformation. These internal stresses are, therefore, one cause of work hardening. The other cause acts independently even during a strictly homogeneous deformation of a single crystal, and is due to lattice distortions. This second cause is the only one treated in the modern theory of slip and has been called " atomic strain hardening " by Dehlinger, who claims that it is removed by recovery—i.e., by a low-temperature anneal, whereas the strain hardening due to internal stresses is removed only by recrystallisation.

A statistical theory of the fatigue failure was proposed by Afanasev. The individual grains of a polycrystalline metal will have different flow limits in the direction of the force acting, and they will also be differen tly stressed because of the anisotropy of the crystals, the internal stresses present, the heterogeneities in the chemical and stress conditions (grain boundaries) and the presence of cavities and inclusions. If the frequency curve of the stresses in the grains which are grouped according to the magnitude of the acting forces, is assumed and the increase of the flow stress with the deformation is known, the increase of the flow stress with the number of stress cycles can be calculated. The destruction of the grain takes place when the flow stress increases to the " brittle strength " of the metal.

Orowan connects the mechanism of fatigue with the process of gliding which is essentially inhomogeneous, even in the most perfect single crystal. The basic idea of this theory is that the peaks of the inhomogeneous stress distribution are smoothed out by plastic deformation.

If the material is not brittle but can undergo plastic deformation, such deformation will occur at the stress peaks when this stress reaches the yield point. With increasing external stress more plastic deformation will occur at the stress peaks which will, therefore, increase only slightly due to strain-hardening. Alternating load produces alternating plastic deformation and progressive strain hardening of the material in the neighbourhood of the stress peaks. Initially the material is soft and the plastic deformation is large. With increasing number of cycles the material becomes work hardened and the extent of further deformation decreases. Orowan shows that the plastic deformations during consecutive cycles " decrease approximately as the terms of a geometrical series " ; thus the total strain produced by an unlimited number of cycles is always finite, without respect to whether the strength is finite or not.

FATIGUE PROBLEMS ASSOCIATED WITH AIRCRAFT MATERIALS

By Dr. H. Sutton

IN parts of aircraft, aero-engines and air-borne equipment great endeavour is made by designers to secure satisfactory service performance in parts which are of light weight for their duty. It is very important to recognise those properties and characteristics of metals and alloys which render them able to withstand exposure in fluctuating or alternating stresses and transient loadings of various kinds. Designers are, therefore, interested and concerned in matters such as :—

(*a*) The fatigue properties of the various materials as observed in laboratory tests.

(*b*) The extent to which these properties are affected by surface conditions and treatments, methods of manufacture, etc.

(*c*) The influence of stress-raises such as holes and notches, changes of section, etc.

(*d*) The influence of stress cycles about a particular mean tensile or compressive stress.

(*e*) The influence of stress cycles of differing magnitudes in succession and the influence of rest periods.

(*f*) Means of improving fatigue performance of different materials.

In this paper are discussed a few of the studies of fatigue problems that have been made in recent years, and reference is made to selected fields of investigation. Simple conditions of loading in laboratory tests are discussed particularly with reference to the measurement or comparison of the fatigue properties of light alloys and to different conditions of stressing. Data on the effect of surface finishes on fatigue properties are reviewed. Magnesium alloys and aluminium alloys are very sensitive to the influence of chemical etching treatments, but anodic oxidation treatments of aluminium alloys generally raise the fatigue properties very slightly. The effects of surface conditions resulting from heat-treatment of steels on fatigue properties are very marked and can be very harmful. Fretting and chafing cause low fatigue resistance.

Dealing with the influence of loads occurring in service in the light of available data and research results the author discusses tests of engineering structures and states that it is convenient and customary to apply a stress cycle selected as a suitable one and to apply it repeatedly until fracture occurs or a sufficiently long endurance has been recorded. It is now generally agreed that " under stressing " tends to benefit the more common engineering materials—i.e., stress cycles insufficient to cause failure at very long endurance tend to raise the stress at which failure would result at a particular endurance. It is also generally agreed that " over stressing "—i.e., application of stress cycles such as would result in fairly early failure, in very small numbers may given an improvement in endurance to fatigue stresses but that more frequent application of stresses higher than the fatigue limit causes " damage."

The importance of good design for avoidance of fatigue failure is stressed. Apart from the extensive studies of notch sensitivity, effect of form of notch on stress concentration, effect of fillets at changes of section,

etc., there has been considerable advance in the attack upon the question of improving fatigue resistance of engineering materials. In the case of steels, carburising and nitriding are of outstanding influence.

An increase is recorded of 83% in the Wöhler fatigue limit of a carbon steel, 85% for a 3·5% nickel steel, and 62% for a 5% nickel steel as a result of carburising, the carburised and plain specimens having been similarly heat-treated before being machined for fatigue tests. Test results have also shown that the effect of nitriding was to raise the bending fatigue limit stress of plain specimens by 36% in a 3% chrome-molybdenum steel heat-treated to 67–70 tons/sq. in. and that of notched specimens by 300%.

Other methods of improving fatigue resistance are discussed with special reference to shot-peening, anti-fretting treatments, surface rolling, stress-relieving grooves, stress-relieving heat-treatments, etc. In the case of certain light alloy castings and forgings it has been found inadvisable when high resistance to fatigue stresses is of importance, to use the parts in the condition of heat-treatment which is known to give the highest static strength properties. It is preferable to use them in a stress-relieved condition achieved by solution treatment followed by a semi-annealing treatment at a temperature well above the ageing treatment temperatures that would be selected for optimum static strength properties. The absence of high internal stresses resulting from the modified heat-treatment has proved of great benefit to the service life of highly stressed parts such as forged crank cases, and castings for engine parts.

The author emphasises that in any particular material the fatigue properties are dependent upon general quality. In the case of high strength materials maintenance of the proper standards of composition as regards the desired constituents and the impurities, application of the appropriate technique in melting, casting and methods of manufacture, and in the case of heat-treatable materials application of the correct heat-treatments have to be vigorously observed. Material quality is undoubtedly one of the major factors contributing to reliable performance in fatigue, and without material of satisfactory quality the most careful designers and fabricators cannot achieve their desired quality and reliability of product. Co-ordination of effort between material producer and user is required for most efficient result of their labours, and seldom can the one rectify mistakes of the other.

The study of fatigue properties is a relatively young one and great advances are likely to be made in future years. Leaders in the production of high quality engineering materials will need to know their products and progressive users will need to concern themselves with the stress-bearing characteristics of their structures and of the component materials intimately. A brief glance over the last few years encourages one to take the view that the next few years should yield greater progress.

REPEATED LOADING OF STRUCTURES

By Prof. A. G. Pugsley

IN this paper the scope of the discussion is restricted to the consideration of loads which are repeated at intervals ranging from seconds to hours and at rates which can be regarded as gradual as compared with the natural periods of the structures concerned. Such a definition is appropriate to the varying loads occurring in the structure of an aeroplane in flight, as a result of deliberate manoeuvres or of encountering gusts. The author discusses the magnitude and frequencies of the fluctuating loads occurring in flight, as determined by the statistical analysis of flight load records, and their influence on structural failures in the air.

Dealing with structural failures under repeated loading of an operational type, it is stated that investigations show the repeated loading problem in structural engineering to be primarily a problem of joints. These are the chief source of weakness, and it is the failure of joints—loosening of rivets, "ovalling" of holes, and cracking at points of stress concentration—and in general, failures of joints in redundant structures, which are the main concern of the structural engineer. The author suggests that, in addition to designing in the customary manner for static strength using a "factor of safety," structural engineers should consider the effect of repeated loads and endeavour to fix a life limitation appropriate to each class of structure and to design accordingly.

STRUCTURES LIABLE TO FATIGUE FAILURE AND SOME CONSIDERATIONS IN THEIR DESIGN

By L. R. Jackson and H. J. Grover

INTEREST in the factors contributing towards failure in structures by fatigue has been stimulated by design trends which may require future structural units to withstand repeated stresses in service. Results of experimental work recently carried out in the United States are reviewed in this paper, and a number of the more important considerations such as stress distribution under repeated loads, types of repeated stress, stress concentration, size effect, and surface conditions are discussed.

Evaluation of fatigue life expectancies of many structures is limited largely by lack of detailed knowledge of service stresses and other service conditions conducive to decrease fatigue strength. Any structure subject to repeated loads of appreciable magnitude can be viewed as liable to fatigue failures. Many of these failures in service are noted in a wide variety of structures which have generally been attributable to known factors, and a large percentage of recorded failures appears to have been due, not to miscalculation, but to complete neglect (in design, in fabrication or in inspection) of one or more items known to be important in prevention of fatigue.

Nevertheless, explicit design of structures to resist fatigue may demand more careful consideration in the near future. Trends toward higher dynamic loading are evident in many fields. The problem is particularly interesting in certain aircraft structures where higher repeated stresses may be encountered (due to higher speeds, increased loading and similar trends) but the weight penalties of over-design must be avoided. Both economic and safety considerations make it desirable to estimate life expectancy (whether due to fatigue or other causes) for structural parts and assemblies.

At present, evaluation of fatigue life expectancies of many structures is limited largely by lack of detailed knowledge of service stresses (and other service conditions which may decrease fatigue strength of critical parts). As such knowledge increases, some gaps in present information about the fatigue properties of materials may become more significant. In general, there may need to be more information along these lines :

1. More complete evaluations of the fatigue strength of materials under other loadings than fully reversed bending.

2. More systematic data on the effects of stress concentrations on fatigue strengths of materials.

3. More useful accounts of the damage of materials by overstressing and the strengthening by understressing.

It may be pertinent to raise the question whether the laboratory fatigue tests now most common can supply all the types of fatigue strength data that will be needed in structural design. *To be contd.*

THE FACTORS CONTRIBUTING TO FATIGUE FAILURE IN AIRCRAFT

By C. W. George, S. F. Grover, and B. Chalmers

NUMEROUS methods have been devised for carrying out fatigue tests on materials in the laboratory, and from these tests a very large amount of data has been obtained. The interpretation of such evidence in relation to fatigue performance in service is, however, very complex, and in this paper the authors classify and describe some of the factors involved, particularly in relation to the incidence of fatigue failure of metallic materials in aircraft. They show that the usual method of expressing the results of laboratory fatigue tests affords insufficient data for aircraft designers.

The actual fatigue performance in service of a given component will depend on the inherent fatigue properties of the material, the geometry of design, the condition of the surface, the service to which it is subjected, and the environment in which it functions, and the stress sequences to which it is subjected. Present methods of test, because of the stress cycle applied by ordinary laboratory procedure, do not approximate at all closely with those met with in service. It is desirable that a stress cycle including occasional high stresses and more frequent lower ones should be applied in order to obtain the numerical information that could be used by a designer. The appropriate cycle should, of course, be determined from measurements on a component undergoing service similar to that contemplated.

Although the value of laboratory fatigue tests as a guide to designers leaves much to be desired they do provide the opportunity to investigate separately the influences of the numerous variables referred to in the paper. The knowledge of these influences should enable designers to get the best results from their materials even if they are not able to predict definitely what the actual fatigue performance in service is going to be. There is no cause for alarm on the score of fatigue in aircraft at present, but as designs become still more efficient, it is likely that fatigue troubles may increase, and it is, therefore, most desirable that all the factors affecting fatigue performance should be appreciated and applied.

A Metallurgist in Tanganyika

By J. H. Harris, B.Sc., A.R.S.M.

THE way in which an enterprising Colonial government can assist its mining industry from a technical point of view was well brought out in a recent lecture at the Imperial Institute by Mr. Harris, B.Sc., A.R.S.M., of the Geological Survey Division, Department of Lands and Mines, Tanganyika Territory. As he explained, the establishment of a Metallurgical Advisory Service in Tanganyika for the benefit of the "small worker" was unique in the Colonies. Sir Edmund Teale, who presided at the lecture, himself conceived the idea more than a quarter of a century ago when he was Director of the Geological Survey of Tanganyika. In 1926 the Geological Survey was founded, and since 1930 a laboratory service has been available to the mining community in general.

For a number of years, however, the laboratory service was run single-handed by the late Mr. Frank Oates, but by 1935 the volume of work had grown so much that Mr. Oates asked for an assistant. By this time the alluvial diggers in the Lupa goldfield had turned to reef production, but had found difficulty in treating what it had become the fashion to term "refractory ore", and were appealing to the Geological Survey for help. It was therefore proposed that the new assistant should be a qualified metallurgist who would be able to help these small workers, and the lecturer was appointed to this post in 1935.

It was in the same year that the Geological Survey was merged with the Department of Lands and Mines. During the period when the location and the erection of its headquarters was under discussion, Mr. Harris visited both the Lupa and Musoma goldfields; the visit to the Lupa goldfield in 1935 being the first inspectional and advisory tour of an East African goldfield by a qualified Government metallurgist. During a second visit to the Lupa goldfield, a temporary laboratory was set up. These visits brought to light a number of interesting and unexpected problems, of which Mr. Harris gave various examples. He noticed particularly that small workers prone to be indifferent to, or sceptical of, the value of scientific methods often become much more receptive of new ideas when these were brought to their notice by actual demonstration.

With the outbreak of war in 1939, the emphasis was first on the stimulating of gold production which entailed more visits to the goldfields, including this time the Iramba. With the advent of "Lease-Lend" the emphasis went off gold, and the Geological Survey undertook the search for and investigation of deposits of strategic minerals. As a result, the Laboratories undertook the testing of ores of lead, copper, phosphate, garnet, kyanite, corundum, graphite, steatite, molybdenum, nickel, manganese, diamonds, as well as gold, and also began investigations on kaolin, salt and coal. Another result of the war was the shortage of building materials in Tanganyika, chiefly cement and corrugated iron, which were imported, and efforts, though unsuccessful, were made to start local production of cement. These led to a great deal of laboratory work on limes, clays, pozzuolanas, Sorel Cement and refractories, and a considerable amount of useful information was obtained. Among valuable work done was the setting up by the Geological Survey of a small factory for making abrasives from local corundum, its most important products being stones for sharpening knives used for tapping rubber trees, and also the setting up of a small slate-pencil factory. An important, though indirect, result was the increased recognition of the usefulness of the Geological Survey, and the subsequent granting of a large sum of money for the development of the laboratories.

Modern Methods of Gas Analysis

Part III.—Analysis of Blast-Furnace Gas

By W. D. Vint

Discussed in this section are the modified Orsat apparatus and the portable Orsat. The method of taking a flue gas analysis is described, and a brief description is given of the Hempel apparatus.

AN attempt was made in the previous article of this series to present the Orsat apparatus as an instrument capable of dealing with most gases either illuminating or heating likely to be met with in factory or works. The procedure for dealing with the analysis of a coke-oven gas was outlined, the reason being that coke-oven gas possesses a full complement of constituent gases and by knowing the procedure for this gas, all other gases can be easily analysed.

There is one exception to the above rule. A blast-furnace gas (average composition: CO_2 10%, O_2 nil, CO 29%, H_2 2·5%, N_2 58·5%) would entail the elimination of CO_2 in the usual manner by absorption in caustic potash solution, and oxygen by absorption in alkaline pyrogallol. It would be unwise to absorb the carbon monoxide in cuprous chloride solution as insufficient combustible gases would be left to create an explosion for the estimation of the hydrogen. Some of the gas containing a mixture of CO, H_2 and N_2 should be bypassed into the pyro pipette and the appropriate number of ccs. retained for an explosion. Add the theoretical number of ccs. of oxygen (+ 100%) necessary for complete combustion and pass a spark. Measure the contraction and absorb the CO_2 formed in KOH solution. The calculation is as follows:—

Readings	100 ccs. taken for analysis
(1) After CO_2 absorption	90·3
(2) After O_2 absorption	90·3
(3) No. of ccs. for explosion	40·2
(4) After adding oxygen	60·7
(5) After explosion	52·5
(6) After absorption in KOH	38·5

CO_2 is obviously 9·7%.

O_2 is nil.

CO is $\frac{14{\cdot}0 \times 90{\cdot}3}{40{\cdot}2} = 31{\cdot}4\%$

H_2 is $(60{\cdot}7-52{\cdot}5)-(52{\cdot}5-38{\cdot}5)\times\frac{3}{2}\times\frac{90{\cdot}3}{40{\cdot}2} = 1{\cdot}8\%$.

N_2 by difference = 57·1%.

Therefore, complete analysis is:

	%
CO_2	9·7
O_2	Nil
CO	31·4
H_2	1·8
N_2	57·1

Similarly to the above, other mixtures of carbon monoxide and hydrogen or methane and carbon monoxide can be exploded and estimated. If carbon monoxide is present with comparatively high quantities of methane (above 5%) and hydrogen (above 15%) the carbon monoxide can be absorbed in cuprous chloride solution and the other combustible gases exploded singly. From the fundamental equations:

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$
$$2H_2 + O_2 = 2H_2O.$$

the individual constituent can be calculated. This method is more accurate than the method including the combustion of carbon monoxide.

Sometimes a gas containing a quantity of combustible gas too small for explosion purposes is encountered. Assuming no satisfactorily wet methods are available (e.g., in the case of methane) the gas can be analysed by mixing with it a number of ccs. of pure hydrogen or any other combustible gas. Add the appropriate number of ccs. of oxygen or air, explode, and carry out the usual procedure. The calculation now involved is quite simple.

Example No. 1.—Suppose 18·2 ccs. of a residual gas (after eliminating CO_2, O_2 and CO, etc.), and bypassing the major part of the gas into the cuprous chloride solution) failed to explode, and it was known that a small quantity of methane was present. Shunt into the burette about 6·0 ccs. of hydrogen and measure accurately. Now add about 15 ccs. of oxygen and remeasure. Explode, remeasure, absorb in KOH and measure again. The number of ccs. CO_2 absorbed is equal to the number of ccs. methane present in 18·2 ccs. of residual gas, and from this the percentage of methane in the sample can be calculated.

Example No. 2.—Assume that a gas from which has been extracted all the other constituent gases refuses to explode when mixed with oxygen, and it is known that a small percentage of hydrogen is present. Add about 10 ccs. of pure hydrogen and about 10 ccs. of oxygen and explode. Remeasure the gas volume accurately at each operation. Suppose the readings are as follows:—

38·6 ccs. of gas.
48·9 ccs. after adding H_2.
50·0 ccs. after adding O_2.
33·2 ccs. after explosion.

The contraction due to adding 10·3 ccs. of hydrogen is 15·45 ccs. The actual contraction is 16·8 ccs.

Therefore, contraction due to unknown quantity of hydrogen is 16·80–15·45 = 1·35 ccs.

And 1·35 ccs. contraction represents the contraction occurring when $1{\cdot}35 \times 2/3$ ccs. hydrogen explode.

That is 0·9 ccs. H_2 are present in 38·6 ccs. of the residual gas. The percentage of hydrogen in the original sample can then be easily calculated.

Example No. 3.—A gas contains small amounts of hydrogen and methane. The procedure is exactly the same. Transfer about 40 ccs. of the gas into the gas burette, add about 10 ccs. of hydrogen and about 10 ccs. of oxygen. Explode, remeasure contraction and absorb in KOH. Assume that the readings are as follows:—

39·3 ccs. of gas.
49·5 ccs. after adding H_2 (i.e., 10·2 ccs. H_2)
49·9 ccs. after adding O_2 (i.e., 10·4 ccs. O_2)
33·4 ccs. after explosion.
33·2 ccs. after absorbing in KOH.

(1) Methane present in 39·3 ccs. of gas is 33·4–33·2 = 0·2 ccs. Percentage methane can be easily calculated in the total sample.

(2) The total contraction is 16·5 ccs.

The contraction due to the total hydrogen alone is 16·5–2(33·4–33·2) = 16·1 ccs.

The contraction due to the 10·2 ccs. H_2 added is $10{\cdot}2 \times \frac{3}{2} = 15{\cdot}3$ ccs. Therefore, contraction due to unknown H_2 is 16·1–15·3 = 0·8 ccs. Therefore, H_2 present in 39·3 ccs. of gas $0{\cdot}8 \times \frac{2}{3} = 0{\cdot}53$ ccs. From this the percentage hydrogen in the original sample can be calculated.

Modified Orsat Apparatus

The Orsat apparatus described in the previous article of this series has several disadvantages which have been eliminated in the later modified forms. The Hornby apparatus illustrates a good attempt at improving these derogatory features. Referring to Fig. 1, which provides a pictorial illustration, it may be observed that the following advantages are well in evidence.

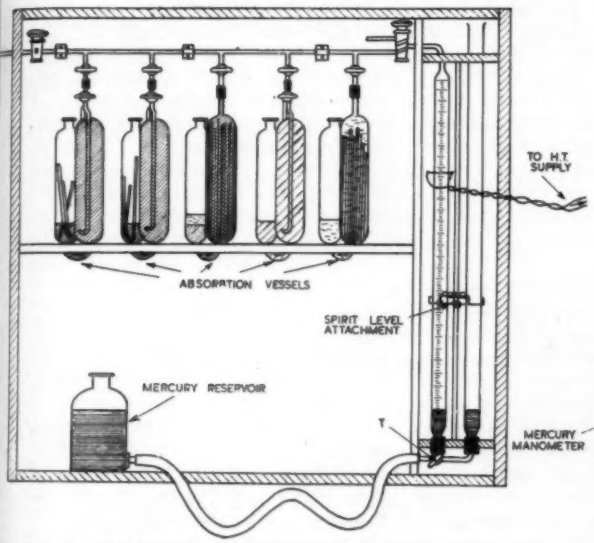


Fig. 1.—The Hornby modified Orsat apparatus.

(1) Confining liquid being mercury, there is no possibility of gas absorbtion before the gas reaches the reagents.

(2) Three way cock at T and branch limb for a manometer tube which together with the hair line and spirit-level attachment provides means for obtaining extremely accurate readings at atmospheric pressure. Inaccuracies due to misalignment of mercury levels are thus obviated.

(3) Explosions are carried out in the graduated burette, which for most purposes is advantageous.

(4) An additional and finer control on the rate at which the gas is forced into the absorbents is provided by the tap at T.

One of the disadvantages which this model possesses as compared to the previous Orsat is the fact that the gas burette is not water jacketed. Care should be taken during an analysis to ensure that the sun or any other source of heat is not allowed to impinge directly upon the apparatus. Volume increases with resultant gross inaccuracies of measurement are extremely probable if this precaution is not taken.

A point which must be watched in connection with the apparatus—if bromine water is used for absorption of unsaturated hydrocarbons, the vapour must not be allowed to come into contact with the mercury. Pass the gas in the usual manner into the bromine pipette; attach rubber tubing with bung into the back of the KOH pipette and open both bromine and KOH pipettes. By means of bellows or the mouth, the gas can be passed alternately into bromine and KOH pipettes until the unsaturated hydrocarbons are dissolved. When this stage is reached, pass the gas into the KOH and leave for a few minutes. Pass back into the burette and measure decrease in volume which represents the percentage of unsaturated hydrocarbons.

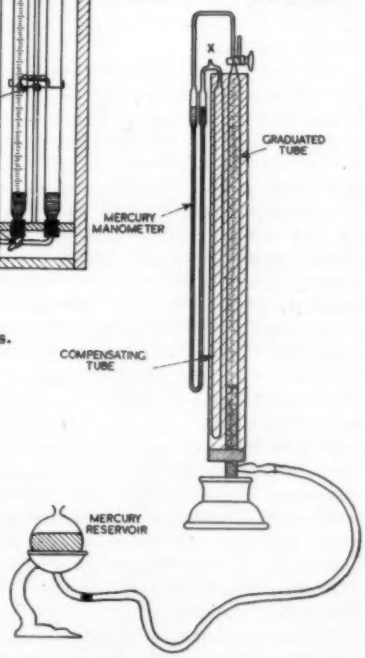


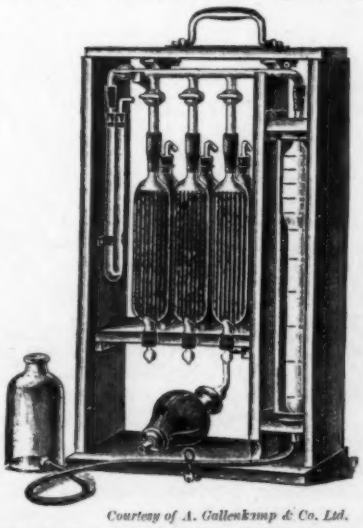
Fig. 2.—The Hempel apparatus.

Portable Orsat Apparatus

Although the Orsat principle is the oldest in gas analysis, there has been little so far to surpass this apparatus for quick and fairly reliable analyses. This fact is even more pronounced in the case of the smaller portable form of the apparatus which has proved invaluable in countless works and factories.

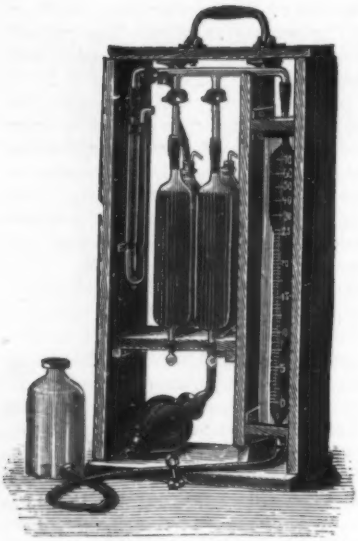
In appearance and principle the portable apparatus is like the larger bench model, the main difference being that no arrangement is made for the estimation of H_2 and CH_4. The apparatus consists merely of a water jacketed graduated gas burette and two or three gas pipettes, No. 1 for KOH, No. 2 for alkaline pyrogallol, No. 3 for cuprous chloride solution. This apparatus is used mainly for the spot sampling and testing of flue gases. The great advantage of this type of instrument is that after a flue gas has been sampled and analysed, probably within less than 10 minutes, adjustments to the boiler or furnace as the case may be can be carried out and a further analysis made, this again within a few minutes. This process can be carried on until pretty near perfect combustion is achieved.

The intake to the gas burette is usually provided with a filter, the purpose of which is to prevent solid particles from the flue reaching and clogging the gas burette. For simplicity, pipettes of the glass tube principle are usually provided this obviating the necessity for extra cocks. A small tin containing tap grease should be carried in the apparatus in case a sticky tap is encountered on the job. Corks should be inserted in the back limbs of the gas pipettes, whilst the apparatus is not in use; this prevents: (1) Reagents spilling from the pipettes whilst the apparatus is being carried; and (2) deterioration of reagents by



Courtesy of A. Gallenkamp & Co. Ltd.

Fig. 3. Orsat-Fischer's portable gas analysis apparatus with three absorption vessels



Courtesy of A. Gallenkamp & Co. Ltd.

Fig. 4.—Orsat-Fischer's portable gas analysis with two absorption vessels.

the action of the atmosphere. A cork should also be inserted in the levelling vessel, and removed only when the apparatus is in use. When carrying out analyses, if possible, stand the apparatus in front of a source of diffused light and accurate readings on the gas burette can then be made.

The most convenient method of sampling a flue gas is as follows: Fill the gas burette with liquid by raising the reservoir and opening three-way tap to atmosphere. Close tap and lower reservoir. Attach bellows to bottom branch line from tap and open tap such that inlet to apparatus is connected to bellows. The flue gas is now drawn along the sampling pipe and blown into the atmosphere from the bellows. When the pipe is clear of air turn the three-way tap so that the pipe is connected to the top capillary of the apparatus. Flue gas will now enter the gas burette, and when a little more than 100 ccs. have been collected, close the three-way tap. By levelling the reservoir and opening the three-way tap momentarily, the level can be brought as near as possible to the 100 cc. mark. The analysis of the gas can now be made in a similar manner to that of the bench model Orsat.

The Hempel Apparatus

This apparatus can hardly be said to fall within the category of modern instruments, but nevertheless a brief description is warranted on the grounds of its great utility for the analysis of most industrial gases. Many laboratories use the Hempel and providing care is taken, extremely accurate results can be obtained. The apparatus depends upon the same principal as that of the Orsat—measurement by volume of the gas, and absorption of its constituents in suitable reagents. One may regard the Hempel as a kind of exploded Orsat. Each integral part—the measuring burette, absorption vessels, explosion tube, are all separate, and temporary connections between the measuring burette and gas pipettes are made for the transference of the gas.

The older type of Hempel used an ordinary plain graduated tube for the gas burette. This tube has now been superceded by the type as shown in the illustration. With the latter arrangement, effects of changes in pressure and temperature which may occur during an analysis are compensated; it consists essentially of four parts:—

(1) 100 ccs. gas burette graduated in tenths of a cc.

(2) Ungraduated tube of same capacity known as the compensating tube.

(3) Manometer and water jacket.

(4) Levelling jar and mercury.

The purpose of (1) is obviously to hold the gas. The compensating tube is filled with air, mercury added to the manometer and the point "x" sealed; the air enclosed is subject to the same pressure and temperature fluctuations as the sample of gas and thus exerts an equal and opposite pressure. Changes in volume due to variations in conditions of temperature and pressure are, therefore, compensated.

The incorporation of the manometer is a simple method by which the gas contained by the gas burette and the air in the compensator or correction tube as it is sometimes called are balanced. The water jacket ensures that no violent temperature fluctuations affect the gas.

The compensating tube may be used in either of two ways. An indeterminate amount of air may be enclosed within it by simply fusing the point "x" so that the volume in the compensating tube will correspond with the prevailing barometric pressure and temperature at the time of the operation. On the other hand, the tube may be filled with an amount of air such that the apparatus directly indicates gas volumes reduced to normal temperature and pressure. If the former arrangement is made, prevailing barometric pressures and temperatures must be taken so that gas volumes may be corrected if necessary.

The vessels containing the reagents and the explosion or combustion tube are mounted on separate stands. After the initial volume reading of a gas has been taken on the gas burette, the latter is connected by rubber tubing (glass to glass within the rubber being maintained) to the particular absorption vessel, the levelling jar is raised, and the gas forced into the absorption vessel. The pinch clip on the latter is now released and the absorption vessel gently shaken with both hands. When sufficient time has elapsed for the absorption of the particular gas, the vessel is again connected to the burette and by a reversal of the process, the gas is forced back into the burette. Measurement of the volume is now made. This procedure is repeated for the absorption of each constituent gas, soluble in reagents.

Explosion or combustion as the case may be is made in a similar manner by transferring the gas to the explosion bulb and back again. The chief disadvantage of this apparatus is the error likely to be encountered as the gas is transferred from one part of the apparatus to another. The whole accuracy depends upon the absence of leaks during the constant bending and pinching of the rubber joints.

Notwithstanding, a very thorough absorption of the gases can be made in this manner. As the gas is transferred from the reagents to the burette, the tap must be reversed to connect with the manometer and the mercury levels in the latter must be on the same horizontal plane. Except for temperature and pressure corrections, all the calculations for the constituents of the gas are the same as those of the Orsat apparatus.

Mr. Malcolm Dunbar has retired from his position as Managing Director of L. Oertling, Ltd., after 40 years' service with this firm, 28 years of which he was managing director. His direction of this firm has coincided with major developments in balance technology, and it is interesting to reflect that, even in the inter-war period of acute German competition, Oertlings were able to pioneer and develop numerous improvements. These include the aperiodic, prismatic-reflecting balances now in general use for analytical and research work, and also modern, reliable micro and semi-micro balances for the new techniques of micro and semi-micro analysis.

Mr. Dunbar's many friends, in both scientific and social circles, will wish him all happiness in his retirement from L. Oertling, Ltd., and success in the other business interests with which he will continue to be associated.

Correspondence

Aluminium Finishes

The Editor, METALLURGIA.

Dear Sir,

I read with great interest the article on "Aluminium Developments," by S. A. J. Sage, in your February issue, especially the section on surface finishes, which is my special fie'd.

I was rather pleased to note his mention of chromium plated aluminium where high abrasion and non-sticking properties are required. Chromium is exceptionally good in this respect, on account of its excessive Brinell hardness (800–1,000), and its low coefficient of friction (30% lower than any other common metal). It must, however, be clearly realised that, for the chromium deposit to fulfil this function, the chromium deposit must be of sufficient thickness (over 0·002 in. and preferably about 0·005 in.), in order to prevent any cushioning effect by the underlying aluminium base. Unless this minimum thickness (0·002 in.) is applied, a large proportion of the value of the chromium deposit is lost.

Another ever-increasing use is the application of nickel plus chromium deposits to aluminium alloys. This is gaining great popularity in the decorative world as it ensures a non-tarnishing finish on a relatively non-corroding base. It should be clearly understood, however, that the application of nickel plus chromium deposits is a specialised job, and not one to be undertaken without the advice of specialists in these matters, as even this process is restricted to the number and type of aluminium alloys that can be used.

The author's statement that "The use of dyed anodised coatings is at present very restricted and limited to small size articles," is rather misleading and erroneous. Whilst I agree that the use of dyed anodised coatings is restricted on account of the intrinsic properties of the anodic film and the dyes used, it should always be remembered that the anodic film is restricted to a pH range of about 4–10. Outside this range the anodic film is chemically attacked and often dissolved. It should be borne in mind also that many of the dyes used are susceptible to certain chemicals and to heat. Thus the right type of dye to use, and the correct sealing of the film are very important points. The thickness of anodic film, porosity, sealing and the right type of alloy to use are very important, and all point to the fact that correct anodising and dyeing is a skilled job, and not, as many manufacturers think, an unskilled one. It is on this account that much bad anodising and dyeing is being carried out. In my opinion, a high percentage of the anodising and dyeing carried out in this country would not bear close investigation. This is a pity and greatly to be deplored, as misapplication often ruins a perfectly good process. I stressed this fact to the aluminium producers and dyestuff manufacturers as a result of a considerable amount of research I have carried out in conjunction with these aspects of the process.

The statement that anodising is limited to small articles is quite incorrect, as articles with a surface area of 10 sq. ft. and over, have, and are being anodised and dyed, in several of the highly skilled anodising firms.

I can readily understand why a manufacturer of furniture could not match his colours on large surface areas, as this entails far more knowledge than the average anodiser possesses. It can be accomplished, however, and to prove this, if any of your readers are having trouble in producing good dyed anodised films, I would be only too pleased to collaborate with them in rectifying this trouble.

113, Amberley Road,
Bush Hill Park,
Enfield, Middlesex.
February 20th, 1947.

Yours sincerely,
FRANK TAYLOR

The Editor, METALLURGIA.

Dear Sir,

The comments of Mr. F. Taylor on the surface finishes for aluminium in my article, "Aluminium Developments" are interesting, and his notes giving data on the thickness of chromium necessary to avoid cushioning are greatly appreciated. The development of methods of electroplating aluminium has been greatly accelerated in recent years and now opens up many fields which were formerly closed to aluminium. The "direct on" method of chromium plating has given greater abrasion resistance, chromium plating on nickel has given greater corrosion resistance with more lasting brilliance, and brass plating with its ability for rubber bonding has opened up new vistas. It is appreciated that with each of these developments a new and often more exacting technique has been introduced and only by specialising is it possible to obtain the greatest advantage from these developments.

Whilst Mr. Taylor takes to task my notes on the anodising and dyeing of aluminium he agrees that it has its limitations and that much of that produced to-day could be improved. It is agreed that anodising and dyeing are processes needing specialisation and that to obtain the best results definite control has to be maintained throughout the process. The case where the manufacturer of furniture failed to obtain satisfactory results was not that either the anodising or dyeing were not correctly carried out, but that the control of the process was not exacting enough or had not the latitude to give him exactly reproducible colours. The articles were large, and because of this were processed by specialists having the necessary large equipment and skilled labour, but as the colours were not consistent—the variation could only be seen by critical examination—it was decided by the manufacturer not to start anodising and dyeing developments in his own works, but to enamel and dry the furniture by infra-red rays. Troubles were also encountered due to the crystal structure of the aluminium sheet being very distracting on the large sheets. This, no doubt, could have been avoided by "patterning" the sheets, but this would have raised the production costs of the furniture. It is not doubted that the colours could eventually have been matched, but this would have entailed very rigid control of the process with perhaps the installation of automatic machinery. Time and economic considerations also weighed against the anodising and dyeing process.

Mr. Taylor's offer of advice and help is greatly appreciated.

Langthwaite,
Lancaster.
February 24th, 1947.

Yours sincerely,
S. A. J. SAGE.

Surface Hardening of Aluminium and its Alloys

The Editor, METALLURGIA.

Dear Sir,

I have read the article by Messrs. K. G. Robinson and B. W. Mott in your February issue, with great interest, and would like to make the following comments :

Surface hardening by means of anodising in oxalic or sulphuric acid solutions, providing care is taken to ensure that anodic films are obtained in excess of 0·001 in., can provide a satisfactory case-hardened surface on most of the harder aluminium (copper and magnesium containing) alloys. The main trouble has been in acquiring sufficient thickness. This is impossible with the chromic acid process. I do agree, however, that no marked beneficial effects on the fatigue or creep properties are obtained.

The statement that " hard electroplated coatings of chromium and nickel on aluminium alloys have not proved successful " is rather misleading, as, on certain specific types of work, both types of deposits have been used. Chromium-plated aluminium pistons, piston heads and other aircraft parts have been and still are being used. The use of these deposits is dependent, of course, upon two main factors :

1. The quality of finish required.
2. The operating conditions.

Under (1) it can be roughly stated that the best deposits, having high adhesion, are on a slightly roughened surface of the base metal. This means that if a perfectly smooth chromium deposit is required, the adhesion normally suffers, as less roughening can take place. This roughening is a purely relative term and is, in many cases, only perceptible under strong magnification. It must also be remembered that for chromium deposits to have any surface hardening value, they must be in excess of 0·002 in., otherwise the much softer aluminium base has a cushioning effect.

Under (2) must be considered the general operating conditions. Temperature, causing different co-efficients of expansion of the chromium deposit and aluminium base, and whether the surface is to be subjected to a sliding action or to impact (chromium is useless under impact).

Many other factors must also be taken into account, as they affect the ultimate value of the plated finish. Thus it can readily be seen that whereas chromium plating is an efficient case-hardening process in certain cases, in others it is useless, and therefore, each case should be studied on its merits.

With regard to the copper plating of the aluminium alloy, two points rather intrigued me—namely :

1. The use of the Travers Process.
2. The use of an acid copper solution.

Both the above are contrary to general applications, as numerous tests have proved that the Zincate process yields better bonding than the Travers process, and that the use of controlled weakly alkaline pH copper solutions provide better bonding copper deposits.

One of the snags with the Travers process is that the voltage required, 50 volts A.C., is outside the range of most plating shops, but the main objection is that unless the anodic film, so produced, is broken down to the correct depth by the modifying treatment in sodium cyanide (i.e., in order to ensure that there is sufficient porosity in the anodic film to allow an initial non-continuous deposit of copper at these pores, which is made homogeneous by subsequent bridging across the anodic film) a poor and non-uniform deposit of doubtful adhesion occurs. With the Zincate treatment, which is a chemical immersion treatment, this does not occur and the thin zinc deposit so produced is an excellent base for the subsequent copper deposit.

Anodic films and aluminium are attacked at pH ranges outside 4–10, and the copper sulphate solution used in these experiments would tend to attack the basis metal. This may be the explanation of obtaining such good copper deposits on the oxalic film because of the acid copper solutions having a further modifying effect on the film. The copper solution which is normally used, however, is one containing a high tartrate content and a low free cyanide or the more recent pyrophosphate copper solution. The hardness of the copper deposit can be altered from 56 to 100 Brinell to suit the requirements.

I must, however, state that apart from the above comments I found the paper extremely interesting, and I should like to compliment the authors for presenting a new approach to the surface hardening of aluminium and its alloys and on some fundamental research work that may have a wide application in the near future.

Bush Hill Park,
Enfield, Middlesex.
February 25th, 1947.

Yours faithfully,
FRANK TAYLOR.

The Editor, METALLURGIA.

Dear Sir,

We have read Mr. Taylor's letter with considerable interest, and in reply we would like to make the following comments.

We agree that appreciable surface hardening of aluminium and certain aluminium alloys may be obtained by anodising in solutions of oxalic or sulphuric acid, but we always understood that the presence of copper in the alloy markedly reduced the hardness of the coating. We were aware that hard electroplated deposits of nickel and chromium had been used in certain cases on aluminium alloy parts for aircraft, but their application has been strictly limited.

With reference to our application of Travers method for copper plating, our experiments showed that excellent adhesion could be obtained which resulted in uniform diffusion at 500° C. It is appreciated, however, that other methods of plating might give equally good results.

Royal Aircraft Establishment,
Farnborough, Hants.
March 10th, 1947.

Yours faithfully.
K. G. ROBINSON,
B. W. MOTT.

Production of Cemented Tungsten Carbides

The Editor, METALLURGIA.

Dear Sir,

The article by Stuart H. Brierley on the above subject in your March issue may give a fairly correct outline of the subject, but it errs in detail to a great extent, and does not, therefore, describe British, American or

German practice. According to the author, tungsten powder is made from the oxide by reduction with charcoal in hydrogen at a temperature of 1,400° C. He is apparently confusing two distinct processes. Tungsten used in sintered carbides is usually made by reduction of the oxide in hydrogen without the addition of carbon at temperatures around 900° C. Alternatively, impure tungsten used in steel-making is made by reduction with carbon at 1,300°–1,400° C., and here a reducing atmosphere is usually used only when the charge cools down ; this tungsten is coarse-grained and is not suitable for high-quality sintered carbides.

It is not usual to add a wetting agent (alcohol or water) when mixing tungsten and carbon, and I can see no advantage in doing so. In any case, if this were done, the mixture would have to be dried in a non-oxidising atmosphere, otherwise oxidation of the tungsten might occur.

Considering only alloys of tungsten carbide and cobalt, the most commonly used composition is 6% cobalt, although commercial alloys vary from 3–20% cobalt according to the application. The author infers that titanium (it should, of course, be titanium carbide) is added only for machining very hard steels, whereas it is added for machining all steels. The present day use of compositions containing vanadium and boron is negligible, and the author would have been more justified in mentioning tantalum carbide as an addition to commercial alloys.

Possibly the statement that pressures may be as much as 300 tons/sq. in. can be attributed to a typographical error. In general, the practical range of pressures used in the cold-pressing process is 1–30 tons/sq. in., with a preference for 2–10 tons/sq. in.

The first sintering operation (known in the industry as " pre-sintering ") may be done at temperatures as low as 600° C. ; the use of temperatures around 1,000°–1,100° C. would give a very hard product unless the time was extremely short, and there are disadvantages in this.

The author omits any reference to one of the most important features of the cold-pressing (double-sintering) process. During the final sintering, considerable shrinkage (20–30%) takes place, and, although its extent can be calculated, it does not always occur equally on all dimensions. The pre-sintered piece can be machined accurately, but unexpected variations in contraction result in dimensional errors. It is, therefore, not true to say that the piece " only requires polishing after the second and final sintering."

Long experience in the manufacture of sintered carbides has shown that the hot-press method may be cheaper for simple shapes only when small outputs are required. For large outputs, such as are produced by this Company, the cold-pressing process can be so mechanised and become so continuous that its advantages entirely outweigh those of the hot-pressing process. It is not a fact that the latter process gives higher densities ; when this has apparently been the case, analysis has shown that some of the cobalt has been squeezed out of the alloy. The advantage of hot-pressing is in the manufacture of large pieces where the pressure required in cold-pressing would be too great and the sintering furnace would be impracticably large.

The author's nomenclature in this article is not that usually used in the industry. The process using pre- and final- sintering is known as the " cold-press " process to distinguish it from the " hot-press " process. In what the author calls the " double sinter " process, it is not essential to use two sintering operations ; pressed pieces can go straight to the final sinter furnaces when shaping operations are not required.

Yours faithfully,
for HARD METAL TOOLS, LTD.,
E. J. Sandford,
Senior Metallurgist.

Torrington Avenue, Coventry.
April 4th, 1947.

The Editor, METALLURGIA.

Dear Sir,

Being engaged in an investigation of the methods of manufacturing cemented tungsten carbide, the undersigned were particularly attracted to the contribution by S. H. Brierley which appeared in your March issue. After careful perusal we fear that we must disagree with some of the statements made.

In describing the general effect of sintering, your contributor asserts that a mixture of tungsten carbide powder and cobalt powder are heated to a high temperature " . . . which causes the tungsten carbide particles to shrink and the cobalt to flow . . ." Is it likely that any shrinkage would occur in the particles when one considers that they have already been treated at a similar high temperature for some time during carburising ? Our impression is that the shrinkage which occurs during sintering merely involved a closer association or consolidation of the relatively loosely packed particles. The sintering occurs between the faces of the particles where cobalt, previously coated on to the particles. flows and cements the particles together. Incidentally we prefer not to regard the tungsten carbide powder as an alloy but as a definite chemical compound having the general formula WC.

We find the discussion of the various ball milling operations to be somewhat confused and misleading. The information on times of ball milling is conflicting, and the objects to be achieved by each of the milling operations do not conform to our understanding of accepted ball-milling practice. For instance, we were not aware that during the ball milling of the mixture of tungsten carbide powder and cobalt powder any direct endeavour was being made to reduce the particle size. The chief object is surely to coat each carbide particle with a layer of cobalt so that, in subsequent sintering, effective cementing of the particles is obtained.

Regarding the value of various additions to tungsten carbide, it is well known that where cemented carbides are to be used for the machining of steels (all steels—not only hard steels) titanium carbide (not titanium) is invariably added, whilst for special purposes vanadium carbide and boron carbide are known to be added.

Considering the double-sinter process, we are surprised at the high pressure recommended for compacting the powder mixture in the mould. In our experience it is unnecessarily high and we would like to suggest that the pressure need never, under any circumstances, exceed 10 tons/sq. in. For manufacturing small wire-drawing nibs, the use of pressure of the order of 300 tons/sq. in. may be acceptable, but imagine the size of the press that would be required for pressing slabs of, say, 4–5 sq. in., as is standard practice in the manufacture of tool tips !

In conclusion, although we agree that a non-technical

review of such a highly specialised industry is important, in order to familiarise technicians with the subject, we fear that in this instance over-simplification may have given a false impression. Production chiefs are apt to accept any information which appears in print rather than the advice of their own technical staff, and such a review as this may tend to be very embarassing to the latter.

Yours faithfully.

DAVID BROWN & SONS (HUDDERSFIELD), LTD.

E. Ineson, N.W. Read.

Park Gear Works, Huddersfield.
April 9th, 1947.

The Editor, METALLURGIA.

Dear Sir,

I have read your correspondents' comments on my article with great interest and some dismay. During the last few years I have been engaged on the production of tungsten carbide products, mainly in the form of dies, and have found that engineers generally do not understand the processes adopted in production. This experience prompted me to prepare a brief outline of the processes, neglecting details and using expressions which were believed to be more readily understood by engineers than the technical nomenclature used by metallurgists engaged in this field. It would seem that in seeking simplification a false impression may have been given, and I trust the more detailed information of your correspondents will clarify the subject and overcome any misunderstanding which may have arisen.

With regard to pressures used, I intended to convey that in exceptional cases pressures up to 300 tons/sq. in. may be used, but that rarely did they exceed 30 tons/sq. in., and more frequently were they much less. Even the addition of other elements was only referred to as indication that the finished product rarely comprised tungsten carbide and cobalt only but that additional elements were used to meet special requirements.

Your correspondents have presented much more information than I intended to convey, and it will undoubtedly interest a wider section of your readers, but, while hoping that the broad outline given in my contribution will not embarrass manufacturers of tungsten carbide products, I trust that the main objective of the contribution will not be impaired.

In conclusion, may I express my appreciation of the able manner in which they make their comments, on the major part of which I agree.

Manchester. Yours faithfully,
April 12th, 1947. S. H. BRIERLEY.

Nuffield Foundation Scholarships

MR. K. J. IRVINE, assistant lecturer in metallurgy at the University of Leeds, has been awarded a Nuffield Foundation Travelling Scholarship to enable him to visit the United States and Canada to study latest developments in metallurgical industries. In addition two students of the metallurgical department of this University—Mr. J. G. Parr and Mr. R. E. Cockaday—had been awarded Nuffield Foundation Scholarships to enable them to spend three months at metallurgical works in Canada.

It is noteworthy that out of a total of fifteen such awards made recently by the Nuffield Foundation, three have been made to members of Leeds University. The success achieved is a tribute to the high standing of the Reader in Metallurgy (Mr. A. Preece).

New Magnetic Alloy

A new 35% cobalt—64% iron—1% chromium alloy that carries more magnetism than any other alloy practical for use in motors and generators and is tough enough to withstand intense vibration has been developed by Dr. Trygve D. Yensen, of Westinghouse Research Laboratories in collaboration with Mr. J. K. Stanley. The new alloy, known as "Hiperco," will make possible compact electric motors and generators an estimated 10% smaller and lighter than those of equal power now built for aircraft, because the high magnetic saturation point of this alloy will permit the design of motors with less metal for the same power, or more power from the same amount of metal.

The new alloy is the result of 20 years' research with the final difficulty of brittleness being overcome only recently. Earlier samples were too brittle to be of great use, however, a method of rolling has been devised which enables production of a tissue-thin strip of metal, tough enough to withstand intense vibration and yet ductile enough to be bent double without breaking. Formerly the metal was "hot-rolled" and allowed to cool slowly, but unlike ordinary iron and steel, cobalt-iron becomes brittle when it cools in this manner. It has been found that brittleness can be avoided either by quenching the alloy in cool water or by continuous rolling, while the hot metal cools. With the quenching method in use, ingots are rolled into slabs 2–3 in. thick, reheated to a high temperature, and rolled again to a thickness of $\frac{1}{10}$ in. As the strip emerges from the last set of rolls, it plunges into a trough of cooling water. The sudden cooling makes the metal so strong and workable it can be coiled like wire, whereas formerly it could not be bent at all. The cool metal then goes through a "cold rolling" process which can further reduce its thickness to as little as one two-thousandth of an inch. For most motor and generator applications, however, thickness of approximately one two-hundredth of an inch is sufficiently thin.

Instructional Films on Welding

THE British Oxygen Co., Ltd. have introduced two new 16 m.m. instructional sound films to their film library, which are available on loan to Technical Societies, Institutes, Colleges and other interested organisations. These two films, both of which are of approximately 40 min. length, are the first of a new post-war series to be made by the Company.

The first film is devoted to an explanation of the equipment and precautions necessary for oxy-acetylene welding, and introduces the first exercises which the beginner must practice so as to master blowpipe control, metal manipulation, and the various means of ensuring good fused penetration. In this film a special technicolour section is devoted to illustrating the setting of the blowpipe flame. In the second film, four methods of welding, extensively employed in industry are demonstrated—namely, leftward, rightward and vertical welding with one or two operators, and the special advantages of each are carefully illustrated.

Both films are essentially training films and are intended to supplement the practical experience which alone can make a good welder. They aim to show the important points of good and bad welding as seen through the eyes of the welder, and to emphasise that while bad welds are easily made, good welding is a highly skilled operation.

Colloidal Graphite in the Metal Industry

A useful contribution to speedier production in many ferrous and non-ferrous fields is being made by the application of colloidal graphite. It has been found that it not only facilitates such operations as die casting, extrusion, stamping, wire drawing, etc., but its use, in many cases, reduces maintenance costs especially when applied to parts operating at elevated temperatures. In this article some applications are briefly reviewed.

IT is some years now since colloidal graphite became widely adopted in the metal industry, but in the interval no serious attempt has been made to gather together the technical information which has accumulated, on this subject. Articles on special uses for the product, and papers covering the properties of colloidal graphite, have appeared, from which one can conclude that it is playing an important part in industry in general. The value of this lubricant in the assembly and running-in of petrol and diesel engines has been recognised for years, the practice being standard to-day. The same applies to steam engine lubrication, but in these applications the development has been systematic, coupled with research and investigations.

The Importance of Particle Shape and Size

It is not proposed to do more than refer here to the lubricating effect of graphite, due, as is well-known, to the atomic structure, in which a sheet-like form is produced. This structure makes graphite not only an excellent lubricant but an equally good parting medium. Being resistant to temperatures up to 600° C., approximately, the product is well adapted to the metal industry, with its high prevailing temperatures.

At this point, however, there arises something which may have been overlooked by the industry: the shape and size of the particle of graphite, when colloidalised, and their influence on the performance of the product. If one examines, for example, " dag " colloidal graphite in the microscope the particles, when dispersed in a liquid, are seen to have a plate-like shape, in general. The pronounced scintillation observed in the dark field illustrates this in a striking manner. Many of the particles are also seen to be less than one half of a micron.

Such shape and size offers the two-fold effect of forming homogeneous films which adhere well, when a metallic surface is treated with a dispersion of colloidal graphite in a liquid, such as water or white spirit. It is probably that this superior property of colloidial, as opposed to flaked, graphite has accounted for its wide employment for coating moulds and cores in die-casting, for parting in general, and for high-temperature lubrication where the particles must travel unimpeded wherever the oil carrier goes.

Foundry Moulds

When the dies and cores in pressure and gravity die casting are painted, or sprayed, with colloidal graphite in water, there is formed on the surfaces a thin, adherent film. This provides highly efficient parting, enabling a high throughput of castings, together with high finish. Aluminium and magnesium alloys are now generally cast with such a graphite film as the sole parting medium. After the formation of the initial coating, by two or more applications of colloidal graphite, the graphite film is maintained by occasional applications of the product.

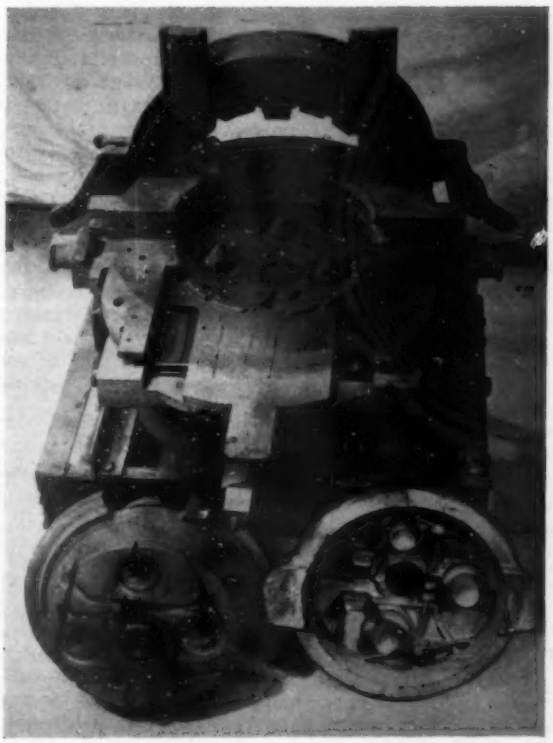


Fig. 1.—Typical die-casting carried out with " Aquadag " as the die dressing.

Some diecasters vary the above practice by forming the initial coating with the water dispersion, but maintaining it with an oil dispersion of colloidal graphite. The same ultimate effect is achieved, this latter practice preserving the dies from rust when in storage. It is noteworthy that the graphite coating, formed with either the water or oil dispersion, can resist temperatures to over 600° C., while it is also an excellent lubricant, assisting the flow of the hot metal in the moulds. Fig 1 shows some typical dies which are treated with colloidal graphite.

Extrusion and Stamping

As might be expected, a graphite surface with the above features is proving useful in extrusion processes. During the war it was found that the life of mandrels

could be increased by a graphite coating on them, scoring being also minimised in, for example, shell production. Here the slippery nature of such a surface is seen to advantage. Involving as it does the movement of one surface over another, under high pressure, colloidal graphite in oil proved equally useful in the stamping of aluminium and magnesium alloys, enabling intricate contours to be lubricated efficiently. One aero-engine manufacturer employed a concentrated dispersion of colloidal in oil for the purpose, applying it sparingly to the more intricate forms.

Filament Wire Drawing

Most of the tungsten and molybdenum wire used for electric lamps and radio valves, is drawn with a concentrated dispersion of colloidal graphite in water as the lubricant. The filament wire is drawn through a trough containing the lubricant, before passing into the diamond or tungsten carbide die. In some processes the lubricant is sprayed as a fine jet on to the wire before passage into the die, while sometimes the two systems are combined. It is claimed by the wire makers that this form of lubrication reduced die wear and permits higher drawing speeds.

Other non-ferrous wires can be drawn with colloidal graphite, special mixtures often being used, as for example, in beeswax or in soap. An active interest is being taken in extending the use of the lubricant into coarser gauge wires, while the success in this field has encouraged its application to brass rods and tubes, or wherever dies are employed for high-grade drawn or extruded products.

High-temperature Lubrication

Having proved of inestimable value in the lubrication of the working parts on die-casting machines, automatic glassware machines, where colloidal graphite is used, it is natural that this lubricant should offer advantages in high temperature lubrication in the field of heavy engineering. It has been standardised for some years now for lubricating the chains and moving parts of kiln cars and annealing ovens, while in bakery ovens it is customary to employ a dispersion of colloidal graphite in white spirit or other light carrier, which will evaporate without smoking.

The links of burden chains, and hot rubbing faces in presses find the high-temperature properties of the graphite film of much assistance, providing as it does a lasting form of lubrication.

Being so finely divided, colloidal graphite can be employed wherever oil is used, for the particles will pass with facility through felt and other types of filters, and behaves, for all practical purposes, as though it were part of the oil. This helps to explain why it has superseded powdered graphite in so many uses.

Notes on this subject would be incomplete without a reference to the growing technique of forming dry, adherent graphite films on metal and non-metallic surfaces, with volatile dispersions of colloidal graphite, such as those in acetone, alcohol and white spirit. These are generally painted, or sprayed on to surfaces, the liquid carrier evaporating to leave the film, which can be used for lubrication, parting or other purpose.

Mention may be made of the fact that brass foundry foundries in the United States are making more use of colloidal graphite as a parting as well as a dressing, this field being formerly covered by powdered mould dressings, from which it would seem that there are possibilities for this technique in other than the higher grade sections of the metal industry. In the United Kingdom experiments are proceeding in a number of processes to determine the technical and economic advantages of colloidal graphite in casting, extrusion and drawing. It has already proved eminently successful for certain deep drawings operations.

The Physical Society's Exhibition

THOSE who had the opportunity of visiting the 31st Annual Exhibition of the Physical Society, recently held at the Imperial College of Science and Technology, would be more than interested to note the developments made in scientific and technical apparatus displayed. In the last decade Britain has made considerable progress in the development and production of suitable apparatus for research and development work, and it must have been very pleasing to a great number of those who visited the Exhibition to see how well this section of British industry was progressing. It is not possible to give a detailed review of the exhibits, but mention can be made of some of the exhibits which attracted special attention.

In the Research and Education Section of the Exhibition, for instance, Metropolitan-Vickers Electrical Co. Ltd., showed devices that, though primarily of a scientific nature, foreshadow many interesting developments of great practical importance. In this Section was exhibited a recording dilatometer designed primarily for work on isothermal transformations in steel. Another instrument on view was a multiple beam interferometer for the measurement of the thickness of very thin films, such as films of gold, silica, collodion, etc., used in electron microscopy. Another interesting development is that of "shadow-casting" by the electron microscope. Typical electron micrographs of specimens which had been shadow-cast in this apparatus were on view. A recording electrometer, the primary purpose of which is to record the intensity of the ion current beam in mass spectrometer analyses, also attracted much attention.

In the Trade Section, Metropolitan-Vickers Electrical Co. Ltd. displayed a 50-kV electron microscope which has left the prototype stage and become a standard Metrovick product. The condenser lens focuses the electrons from the hot-cathode gun on to the specimen; the objective lens forms an image of the specimen magnified 100 times at an intermediate plane; the projector lens further magnifies this image 200 times, forming an image on a fluorescent screen situated at the bottom of the tube. This screen can be moved to allow the electrons to impinge directly on a photographic plate. The resolving power (better than 100 A.U.) is such as to allow further enlargement of the photographic image.

Special high-vacuum evaporation plant was also exhibited, suitable for the deposition of gold or other metals in connection with the shadow-casting technique with the electron microscope. British visitors would note that the "Raymax" Crystallographic X-ray Unit had been re-designed to provide facilities for modern techniques. It carries a new adjustable platform for supporting the cameras which facilitates their adjustment and exchange. Another instrument of considerable interest was the controlled spectrographic spark-source unit, and further developments of an experimental equipment is the lamination detector, originally made for the detection of laminations in steel sheet. A new

instrument is used for testing the bearings for satisfactory adhesion of white-metal linings and for testing small brazed joints, bi-metal strips, etc. These represent only a few of the instruments and apparatus displayed by this company.

The need for high-vacuum is of increasing importance in modern industry, and some new equipment of this type was exhibited by W. Edwards & Co. (London), Ltd. Included in these was a new high-vacuum pump known as the Speedivac 1a Rotary Pump. Its fast pumping speeds 1½–2 cu. ft./min. and high vacuum 0·005 mm. Hg. renders it suitable for most laboratory and industrial uses. In particular, it is extremely suitable for backing all types of diffusion pumps. It is noteworthy that this company supply a complete range of diffusion pumps operating with mercury, low vapour pressure oils and other fluids. Before the war it is probable that most of these pumps were imported from abroad, to-day standard pumps are available in this country at speeds from a few to many hundred litres per second. These pumps are, of course, invaluable where important research and industrial projects require the lowest possible pressure and highest pumping speeds. In addition to vacuum pumping units, this company supply high vacuum gauges, and many were on view.

The Research Laboratory of the British Thomson-Houston Co. Ltd., had an interesting display, including crystal rectifiers developed for use in centimetre wave radio and radar equipment, and a rectifier type voltmeter which has been developed with capacitance dividers for extending the voltage range. Probably the most interesting exhibit of this company was the three-phase 3,000 r.p.m. squirrel-cage induction motor with silicone insulated stator windings. This motor was exhibited running on a load of approximately ½ h.p., giving a temperature of about 175° C. on the windings which had been specifically mounted in an open test frame to allow ready inspection of the windings. The insulation consists of silicone treated glass cloth slot liners, silicone treated glass tape on the end windings, glass insulated wire and glass insulated flexible leads, the completely wound stator being impregnated in silicone varnish. This special type of insulation has been incorporated for motors where the nature of the duty or the conditions of operation are such that excessive temperatures may occur, possibly under emergency conditions.

Several interesting instruments were exhibited by Bristol's Instrument Co. Ltd., probably the most noteworthy of these was the "Pyrodictor" proportional electric potentiometer controller. This is an entirely new type of instrument for controlling electrically-heated furnaces and other types of plant at any temperature between 100° and 1,200° C. It is of the direct set type and differs from the orthodox type of electric controller in that the controlled heat input is exactly proportional to the load on the plant being controlled. At the Exhibition this Pyrodictor was shown controlling the temperature of a small over-rated electric furnace. Other instruments included an "Pyromaster" potentiometer unitact electric controller, an "Ampliset" free-vane pneumatic pyromaster potentiometer controller, a low-range draught controller, a "Metameter" remote-recording telemeter, a portable pressure recorder, and an impulse sequence cycle controller. This latter instrument represents a completely new development in the precision timing of any sequences of electrical and mechanical operations on process plant.

Some of the departments of Philips Lamps, Ltd. also had some interesting exhibits. Much interest, for instance, was shown in a flame photometer, by which a method of chemical analysis can be used in determining small concentrations of certain elements, particularly the alkaline elements. The flame photometer exhibited consisted essentially of three parts: An air-gas burner, into which the spray of the sample solution is fed from an atomiser under carefully regulated conditions; an optical system which focuses the light from the burner on a photo-cell, after a filter has selected the desired wave band; and a photo-cell assembly which records a measure of the light intensity, proportional to the concentration of the element being estimated. Among other exhibits of this company were an X-ray diffraction unit, designed and developed for both university and industrial laboratories, and an X-ray spectrometer, which is now available with an automatic recorder enabling quantitative and qualitative analyses of crystalline and certain amorphous substances to be made by X-ray analysis.

An interesting feature was the large number of exhibits to be demonstrated indicating that exhibitors were alive to the value of imparting practical knowledge of the instruments and apparatus displayed. There can be little doubt that results from this Exhibition will do immeasurable good and assist further the progress of Britain's scientific and technical developments in this field.

Wild-Barfield (South Africa) (Pty.), Ltd.

WILD-BARFIELD ELECTRIC FURNACES, LTD., advise us that, in collaboration with Messrs. E. S. Mowat & Sons, who have been their agents in South Africa for many years, they have formed a Company registered in the Union, bearing the above name. with registered offices at 51, Milne Street, Durban, Natal.

The products of Wild-Barfield Electric Furnaces, Ltd., and those of their associated company, G.W.B. Electric Furnaces, Ltd., were widely used before the war and their policy of improving still further the sales and service facilities to customers in important overseas territories is to be commended. The new company will be in a position to give technical assistance to industries throughout the Union and in Northern and Southern Rhodesia and British East Africa. Existing users of Wild-Barfield and Gibbons-Wild-Barfield electric furnaces in these territories, and others interested in modern heat-treatment equipment in their production are invited to communicate with the new Company at the Durban address. The branch offices of Messrs. E. S. Mowat & Sons are also made available to the new Company. It should be noted that personnel from the Watford Works of Wild-Barfield Electric Furnaces, Ltd., already resident in South Africa will be in a position to render similar technical service as that available in Britain.

Powell Duffryn Technical Services, Ltd.

THE Board of Powell Duffryn Technical Services, Ltd., the new Powell Duffryn subsidiary whose formation was announced in our last issue, has now been completed. Mr. Robert Foot is the Chairman and the other Directors are: Mr. Edmund Hann, Chairman and Managing Director of Powell Duffryn, Mr. H. H. Merrett, Chairman of Cory Bros., and of Gueret, Llewellyn and Merrett, and a Managing Director of Powell Duffryn, Mr. J. G. Bennett and Mr. W. L. Boon.

Staff Changes and Appointments

Dr. Hugh Ford has become technical director of the Paterson Engineering Co., Ltd., and has relinquished his position as head of the Mechanical Working Division of the British Iron and Steel Research Association to take up the new appointment.

Dr. F. W. Haywood has been appointed technical director of Wild-Barfield Electric Furnaces, Ltd.

Mr. N. Nicholson has been appointed Chairman and Mr. J. W. Habershon and Mr. R. P. R. Habershon have been appointed joint Managing Directors of J. J. Habershon & Sons, Ltd.

Mr. C. G. A. Taylor, Works Manager of the Llanelly tinplate works of Richard Thomas & Baldwins, Ltd., has been appointed General Manager in succession to Mr. H. W. Wheatstone, who has retired.

Mr. R. E. Berry has been appointed works' Chief Metallurgist of Manganese Brass & Bronze Co., Ltd., Handford Works, Ipswich, Suffolk. He has left Lodge Plugs, Ltd., Rugby, to take up his new position.

Mr. Robert Howatt has been appointed Chief Engineer of the Steel Company of Scotland, Ltd. He joined the Company in 1939 as senior draughtsman.

Mr. W. B. D. Brown, M.B.E., Managing Director of the Glacier Metal Co., Ltd., has agreed at the request of the President of the Board of Trade, to serve on the first Council of the British Institute of Management.

Mr. E. S. Waddington, M.Sc., M.Inst.W., A.M.I.E. (S.A.), Assoc.I.E.E., of Philips Industrial (Philips Lamps Ltd.), has recently been elected a Vice-President of the Society of Engineers. Mr. Waddington is also Chairman of the Reorganisation Committee of this Society, and has been a Member of the Council for some years.

Mr. Ben Thornton has been appointed Assistant to the Managing Director, and Mr. W. H. Day, F.C.I.S. has been appointed Secretary of The Wellman Smith Owen Engineering Corporation, Ltd.

Mr. James H. Ewing, O.B.E., has been appointed Head of an official mission in Tokyo to be in charge of sales to, and purchases from, Japan made on Government account on behalf of the United Kingdom, the Colonies and certain other areas. Mr. Ewing is a director of Dodwell & Co. Ltd., and has long experience of trading in Japan. He served during the war as Lieut. Col. in the R.E.'s, and latterly as Assistant Director of Transportation at the War Office.

Mr. H. R. Peters, formerly sales promotion manager to Messrs. Specialloid, Ltd., has now been appointed as assistant general manager to that Company, and Mr. E. S. Bailey, formerly equipment manager of the Company, has been appointed home sales manager.

Mr. E. A. Fowler, B.Sc., A.R.T.C., of the Faculty of Technology, University of Manchester, has been appointed to succeed the late Dr. J. W. Donaldson as chief metallurgist and chemist with Scotts' Shipbuilding & Engineering Co. Ltd., Greenock.

Mr. Harold Humphries has been appointed to the board of directors of Hadfields, Ltd., Sheffield. He joined the company in February, 1945, as commercial manager and later became a local director. From September, 1939, he served with the Ministry of Supply, Iron and Steel Control.

Mr. Humphries is an executive council member of Sheffield Chamber of Commerce and the British Steel Founders' Association, and is a member of the Iron and Steel Institute.

Mr. F. L. Smith has been appointed chief technical engineer in charge of the Central Engineering Department, and Mr. H. C. Cronk as chief engineer of the Plant Construction Department of Dorman, Long & Co. Ltd. The Company has converted the large hall formerly the home of Middlesborough Exchange, into a spacious drawing office for these two departments.

Mr. F. L. Smith obtained his technical education at Sheffield University, and held technical appointments with various firms including Appleby Frodingham Steel Co. Ltd., and the Skinningrove Iron Co. Ltd. Later joining H. A. Brassert & Co. Ltd., consulting engineers, he assisted in the construction of the Corby works of Stewarts & Lloyds, Ltd. He also carried out investigations on the Continent.

Mr. Harry C. Cronk joined Dorman Long after nine years on the staff of Richard Thomas & Baldwins, Ebbw Vale works. Last year he served as chief of the technical staff with the Control Commission for Germany—Metallurgical Branch. From 1927–1931, Mr. Cronk was chief electrical engineer for the Tata Iron & Steel Co., Jamshedpur, India, after which he was chief of the power development section of Gipromez, U.S.S.R. working on the first and second five-year plans.

Mr. L. Rotherham, M.Sc., has been appointed Head of the Metallurgy Department at the Royal Aircraft Establishment, South Farnborough, in succession to Dr. B. Chalmers. For some years Mr. Rotherham was Head of the Physics Section of the Brown-Firth Research Laboratories, where he served under the late Dr. W. H. Hatfield, F.R.S., and Dr. C. Sykes, F.R.S.

Mr. Alan Bessemer of West Kirby, Cheshire, a great-nephew of the late Sir Henry Bessemer has entered the Carnegie Institute of Technology as a freshman in the College of Engineering and Science. He had been waiting nearly 10 years to enter the Institution founded by Andrew Carnegie, long time friend of the Bessemer family. He made his first application at the age of 14 in 1937. Since then, however, he has been in the R.A.F., and holds the D.F.C.

Mr. W. L. Hall, B.Sc., A.R.S.M., A.I.M., A.R.I.C. has been appointed Chief Officer of the Liaison Department of the British Non-ferrous Metals Research Association, this post having become vacant on the departure of Mr. W. C. F. Hessenberg to become Head of the Mechanical Working Division of the British Iron and Steel Research Association. Mr. Hall graduated from the Royal School of Mines with a first-class honours degree in 1936. After two years experience in a steel works he joined the research staff of the B.N.F.M.R.A. in 1938, working on galvanising, stress corrosion of light alloys and the properties of aluminium-magnesium alloys. In 1944 he was transferred to the Liaison Department where he now takes over full charge.

Reviews of Current Literature

Laboratory Manual in Metallography

WHILE there are many excellent books on metallography there are few which present a series of experiments so usefully as in this book. All universities and colleges in which metallurgy forms part of the curriculum devote much time to metallographic study supported by experimental work. The actual experiments vary but the principles involved are the same. The experiments given in this manual have been used in a series of three courses given to metallurgical engineers over a period of six years. Some have been used over a longer period, but have been thoroughly revised. The experiments are designed to present: (1) The necessary techniques in metallography; (2) the fundamental principles involved in mechanical and thermal treatment of alloys; (3) the common treatments of representative non-ferrous alloys, and (4) the common treatments of representative ferrous alloys.

The necessary techniques are developed in the first four experiments, where studies of the microscope, a representative polishing technique, and the application of photographic principles are made. The next nine experiments cover the more important basic principles of physical metallurgy and prepare the student for the application of these basic principles in later experiments. These include: Microstructure and properties of commercially cast pure metals; mechanism of plastic deformation; cold work and its effect on brass; annealing of cold-worked brass; constitutional diagrams; intermetallic-compound formation and peritectic reaction; age-hardening; and microscopic determination of a solid solubility curve. Thirteen experiments cover representative non-ferrous materials, such as commercial copper and the effect of hydrogen annealing; the effect of zinc content on the properties of alpha brasses; the constitution and microstructure of high brass and Muntz metal; the constitution and properties of copper-tin and copper-silicon alloys; the constitution and properties of copper-aluminium alloys; the heat-treatment of copper-aluminium alloys; zinc and zinc die-casting alloys; the constitution and properties of aluminium-copper alloys; the constitution and properties of aluminium alloys; the constitution and properties of magnesium alloys; the metallography of a heat-treated magnesium alloy; lead-tin alloys, tin plate, and bundy tubing; the structure and properties of bearing alloys. One experiment covers the products of powder metallurgy. Fifteen experiments are on ferrous materials which cover commercially pure iron; the structure of annealed common wrought steels; cast structures in steel castings and welded steel plates; carburised structures; the forming hardenability test; the effect of gradient quench on the microstructure; the products of complete and of partial isothermal transformation of austenite; the effect of time and temperature upon tempered structures; tempering a low alloy steel; high-chromium low-carbon alloy steels; die steels; tool steels; gray, white and malleable cast irons; and the effect of chromium, molybdenum and nickel on cast iron.

There are three appendices giving etching reagents required for the experiments, photographic solutions, and supplies for the metallographic laboratory, together with a list of visual aids. Throughout the manual, data sheets have been provided upon which photomicrographs may be mounted with pertinent data. Graph paper is also provided where required and the sheets are so arranged that all results of the work can be entered in detail. The whole series of experiments is reasonably comprehensive and should give the student a working knowledge of basic principles and acquaint him with the application of these principles to some common industrial metals and alloys. This manual is admirably prepared and will be of great value to students in metallurgy.

By John F. Eckel, D.Sc. and Robert J. Randebaugh, Ph.D.; published by McGraw-Hill Publishing Co. Ltd. Aldwych House, London, W.C. 2. Price 22s. 6d.

Civil Aviation and the Export Trade

Although primarily designed for students who are potentially candidates for the examinations of the Institute of Export, this book will have a much wider usefulness. Air transport has grown so rapidly that all connected with exports should be familiar with its possibilities. Certainly many senior executives in commerce and industry will find in it facts, which they had not fully appreciated in the routine manipulation of this form of transport, and inspiration to emply it with understanding of its advantages and limitations.

There was a time when the use of air transport was confined to goods with a high urgency factor. Among these were news films, newspapers, tools and spare parts of machinery, vital drugs and the like. These items are still found in increasing numbers on the freight manifests, but the importance of air transport is now being realised in a much wider field. The aeroplane, bringing as it does the most distant customer within three days of the research department, the designer, the salesman, or the board room, affords those who will grasp its implications the opportunity of redressing many of the disadvantages implicit in our island situation. Much progress has been made in recent years, and to-day many manufacturers are basing their export programmes on the assumption that part, at least, of their products will reach the overseas markets by air in a matter of hours or days, as against weeks or months by other means.

This book provides useful information on air transport which the enterprising exporter will be quick to grasp and to apply.

By Sq./Leader Norman J. Freeman. Published by the Institute of Export, Royal Empire Society Buildings, Northumberland Avenue, London, W.C. 2. Price 6s. 6d. net.

Definition and Measurement of Gloss

This monograph gives a critical study of the extensive literature on gloss and lustre, and attempts to assess the present state of knowledge of this subject. It is divided into four parts, the first dealing with physical factors influencing our sensations of gloss and lustre. Specular reflexion from plane surfaces and the scattering of light from optically rough surfaces are discussed. The ideal matt surface is described, and the departures from its occurring in practice are illustrated. Real surfaces are considered in detail. Part II deals with physiological and psychological factors which contribute to our sensations of gloss. The different types of gloss recognised by Hunter and Judd are described. There are

sections on binocular and monocular lustre, metallic and vitreous lustre, the "glossy sensation" and various pseudogloss effects. The various attempts at practical gloss measurement are discussed in part III. Our present state of knowledge of the whole subject is summarised in Part IV, which deals with the complete range of gloss, and concludes with a statement of where, in the author's opinion, our knowledge is most deficient and the directions in which future research may most profitably be pursued.

By V. G. W. Harrison, Ph.D.; published by The Printing and Allied Trades Research Association, Charterhouse Chambers, Charterhouse Square, London, E.C. 1. Price 10s.

Controlled Atmospheres for the Heat-treatment of Metals

Too much emphasis cannot be placed on the importance of metallurgical control of all heat-treatment operations in order to develop in the materials the properties desired. Specification requirements have become so exacting in recent years that close control of every process is essential to success in meeting these requirements consistently. It is necessary not only to control the temperature and the rate at which heat is absorbed by the material undergoing heat-treatment, but also the conditions under which the material is heated. In many cases the atmosphere in the furnace is of vital importance, and its control is necessary either to protect the work against scaling or to produce a desired finish on the product. Thus, in the heat-treatment of metals, especially in the ferrous field, controlled atmospheres is now well established on a commercial scale. Bright annealing, bright hardening, gas carburising and nitriding are all processes involving the use of controlled atmospheres, and in this book on the subject, the author not only presents an account of the fundamental principles involved but also concerns himself with the means of applying them in practise.

The use of controlled atmospheres for the heat-treatment of semi-finished material, or of components, is of tremendous value to manufacturers. The main object is to preserve the condition of the surface of the material undergoing heat-treatment, although there are certain exceptions as in gas carburising and nitriding in which the condition of the surface is changed. In this field, the treatment of tool steels, especially those containing molybdenum, emphasises the need for scientifically controlled gas mixtures which cause neither oxidation nor carburisation, but for many other kinds of material, both ferrous and non-ferrous, the use of controlled atmospheres is not less important. The whole subject is very thoroughly considered in this book, and it is presented in a form that it bridges the gap between academic and practical aspects of the subject.

The book is conveniently arranged in three sections, covering respectively the generation, purification and applications of controlled atmospheres for the heat-treatment of metals, and each section is practically self-contained, which will assist readers interested in specific aspects of the subject without detracting from the value of the book as a whole. Six chapters in the first section deal respectively with the history and development of controlled atmospheres; chemical equilibrium and controlled atmospheres; ammonia derivatives; hydro-carbon gases; charcoal-gas generators; and miscellaneous controlled atmospheres. In the second section are five chapters concerning purification of controlled atmospheres; methods for the removal of carbon dioxide; desulphurisation; dehydration; and gas analysis. The greater part of the book is section three, which deals with applications; here special chapters are devoted to low carbon steel; high carbon steel; alloy steels; carburising; nitriding; and non-ferrous metals. It is this latter section which makes this book of very real value, because unless the practical significance of the use of controlled atmospheres is fully understood, errors in application will result. The author has taken great pains in presenting applications which he supports with theoretical considerations which make this book not only interesting but informative to a very high degree. The author has both a readable and convincing style, and the text is admirably supported with illustrations. There can be no doubt that this useful work should be available to all associated with the heat-treatment of metals if only for reference purposes, but a careful study of the subject, as presented, will bring enlightenment to the theoretical as well as the practical heat-treater.

By Ivor Jenkins, M.Sc., with a Foreword by Dr. C. J. Smithells, M.C.; published by Chapman & Hall, Ltd., 37, Essex Street, London, W.C. 2. Price 50s. net.

Changes in the Industrial Diamond Organisation

THE Industrial Diamond Information Bureau originally established in 1943 by the Diamond Trading Co. Ltd., at 32/34, Holborn Viaduct, London, E.C. 1, has been taken over by the Diamond Research Department of Industrial Distributors (1946), Ltd. (Incorporated in the Union of South Africa), and the Bureau will continue to maintain at the same address an up-to-date reference library on scientific and technical aspects of diamond, including patents, and to invite inquiries from users on industrial problems encountered in the industrial use of cutting tools, wire drawing dies, abrasives, and other applications of diamond. The monthly bibliography of literature dealing with matters relating to the industrial use of diamonds will continue to be published, and a free technical service to all industrial users of diamond will, where possible, continue to be offered.

Second Hatfield Memorial Lecture

The second Hatfield Memorial Lecture, founded as a memorial to the late Dr. W. H. Hatfield, F.R.S., will be given by Dr. C. Sykes, F.R.S., of the Brown-Firth Research Laboratories, Sheffield, in the lecture theatre of the Institution of Civil Engineers, London, on May 14th, 1947, at 8-30 p.m. and will be on the subject of "Steels for Use at Elevated Temperatures." Dr. C. H. Desch, F.R.S., President of the Iron and Steel Institute, will occupy the Chair. Tickets of admission will not be required but prior intimation to the Secretary of the Iron and Steel Institute of intention to be present will be appreciated.

WE are advised that OY Hans Palsbo, Unionsgatan, 15, Helsinki, Finland, who represent and are doing good business for four British firms of repute, are desirous of taking one or two further agencies in the iron and steel trade. Mr. Hans Palsbo, the managing director, will welcome inquiries.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

WE have recently been filling in the registration card for the Eleventh International Congress of Pure and Applied Chemistry, which is to take place in London during the summer. Much as we are looking forward to the event, the completion of the card put us in our usual quandary. What is the analytical chemist to indicate as the section or sections in which he is interested? Pure chemistry is represented by sections of Inorganic and Geo-Chemistry, Physical Chemistry, Organic Chemistry. Applied chemists have the remaining ten sections from which to choose. The poor analytical chemist is faced with an all-or-none decision, a decision which, moreover, he would not have to face, we feel, were the Congress being held in the United States of America. (It is not with pride, but with regret that we labour this point). For some time past we have passed, daily, an establishment outside which two men parade slowly bearing a placard reading, "Industrial Dispute: Non-Union Labour." Though we may regard such methods as woefully wasteful of man-power, we have sometimes wondered whether it would help if we employed someone to parade at various—unfortunately at most—chemical meetings in this country bearing blatantly a motto: "Think twice. Here Analytical Chemists are not Recognised." At least our grievance, if not removed, would be advertised in the wider fashion than it merits.

Applications of the Polarograph to Metallurgical Analysis

II.—Polarographic Methods for the Determination of Zinc in Copper Base Alloys*

By G. W. C. Milner

Chemistry Department, University College, Hull.

The effects on the method of all the other elements normally present in bronzes were next studied. Tin is removed as metastannic acid in the opening out, and also some of the iron is co-precipitated with it. Lead is precipitated as the iodide along with the cuprous iodide, whilst nickel is quantitatively left in the filtrate along with the zinc. Traces of iron are also present in the filtrate. Nickel gives a polarogram under these conditions having a half-wave potential slightly more positive than the zinc polarogram. However, nickel is generally only present in bronzes in small amounts compared with the zinc, and, by applying 2 volts across the main potentiometer the nickel curve is just separated from the zinc curve and does not interfere.

Using the calibration graphs constructed from the results in Table II., Methods 2(*a*) and (*b*) have been applied to the determination of zinc in bronzes with the results shown in Columns B and C in Table III.

Traces of Zinc in Bronzes

For the determination of traces of zinc in bronzes of the order of $\leqslant 0{\cdot}10\%$, neither Method 1 nor 2 proved entirely satisfactory. Method 2 gave the most promising results but too much copper was left in solution after the potassium iodide treatment. This caused the oscillations in the zinc polarogram, due to the growth of the mercury drop, to be so large that difficulty was experienced in measuring the true height of the zinc curve on the high sensitivity required for traces of zinc. Better results could be expected by a more complete removal of the copper from solution and the following method was developed for the determination of traces of zinc in bronzes.

Method 3

Dissolve 0·5 g. bronze in 5 ml. nitric acid (sp. gr. 1·20), boil out the nitrous fumes and take down to dryness. Dissolve the salts in distilled water and add 2 ml. 50% sulphuric acid. Make up to 50 ml. in a standard flask and pour into a clean dry centrifuge tube. Pass a rapid stream of hydrogen sulphide through the solution for a few minutes. Centrifuge off the precipitate and transfer 25 ml. of the filtrate by means of a standard flask into a 125 ml. conical beaker. Boil off the hydrogen sulphide, add a few drops of nitric

Continued from page 267, March 1947.

TABLE III.

Number of Sample	Specification or Type	Pb %	Sb %	Cu %	Sn %	Fe %	P %	Ni %	Zinc %			
									Chemical	Polarograph		
										A	B	C
1	B.S.S 383	0·40	<0·02	Rem.	2·80	0·10	—	0·09	1·87	1·80	1·87	1·86
2	B.S.S.1022	0·10	<0·02	Rem.	8·50	0·04	—	0·02	3·91	3·92	3·96	3·95
3	B.S.S.1023/4	2·51	0·19	Rem.	7·35	0·13	—	0·24	5·77	5·75	5·81	5·75
4	B.S.S.1023/4 .. .. (High Nickel)	2·13	0·27	Rem.	7·18	0·28	—	0·87	5·00	4·92	5·02	4·96
5	T.F.F.4	0·15	<0·02	Rem.	10·22	<0·01	0·02	—	1·42	1·39	1·43	1·45
6	B.S.S.898	4·74	0·22	Rem.	4·60	0·01	—	0·24	4·99	4·96	5·00	4·98
7	B.C.S. Bronze "A"	1·83	0·24	85·5	9·96	0·07	0·25	0·04	1·86	1·80	1·88	1·88
8	B.C.S. Bronze "C"	0·41	0·04	86·84	9·80	0·06	0·055	0·09	2·53	2·52	2·58	2·56

The Chemical figures were obtained by precipitating the zinc as sulphide after the removal of all other elements and igniting to the oxide.
The Chemical figures for the B.C.S. samples are those reported on the certificates of analysis.

acid (sp. gr. 1·42) and take down to fumes of sulphuric acid. Cool, add a few ml. water and make the solution ammoniacal by the dropwise addition of ammonia (sp. gr. 0·88). Then add 2 ml. sodium sulphite solution (50 g. in 100 ml. water), 10 ml. base electrolyte A and make the volume up to 20 ml. Pour a quantity of the well-mixed solution into a polarograph cell and add mercury to form the anode. Record the polarogram using a sensitivity of 2 microamperes of the Tinsley polarograph, applying 2 volts across the main potentiometer. Range −0·8 to −1·5 volts.

Results

To 0·5 g. portions of pure copper each dissolved in 5 ml. nitric acid (sp. gr. 1·20) a standard zinc solution was added to give percentages of zinc varying from 0·02% to 0·10%. Method 3 was applied to these solutions with the results shown in Table IV. The graph of the results was a straight line passing through the origin.

TABLE IV.

Zinc %	Height of curve in divisions.	
	S = 2	S = 1
0·02	6·5	12·75
0·04	12·5	25·25
0·06	19·25	—
0·08	25·25	—
0·10	31·5	—

In Method 3 most of the interfering metals are removed by the procedure described. However, any nickel present in the alloy will be present in the final solution along with the zinc. Since nickel gives a curve in base electrolyte A just preceding the zinc curve, the presence of a large amount of nickel in the alloy would ruin the zinc determination by Method 3.

The bronzes received in these laboratories containing traces of zinc only, comply with Specifications B.S.S.369 Grade A or B and T.F.F.5 F or H, and these alloys were also found to contain only very small traces of nickel. Using the calibration graphs constructed from the results given in Table IV., Method 3 has been applied to the determination of traces of zinc in bronzes with the results shown in Table V.

Determination of Zinc in Brasses

The methods developed for zinc in bronzes are also applicable to zinc in brasses, but it was felt that because there is a larger amount of alloying elements in brasses, in particular nickel, manganese, iron, aluminium, besides tin and lead, the zinc precipitation method was most superior, as it removes all alloying metals except lead and manganese.

Method 4

The precipitation of the zinc is carried out on a 2 g. sample exactly as for zinc in bronzes (Method 1). Then proceed as follows: Redissolve the precipitate in 30 ml. 1 : 1 hydrochloric acid, take down to low bulk and make up to 100 ml. in a standard flask. Pipette 10 ml. of this solution into a clean dry beaker, make just ammoniacal, add 10 ml. sodium sulphite solution (50 g. in 100 ml. water) and 20 ml. base electrolyte A and make up to 50 ml. with distilled water. Complete the recording exactly as in Method 1.

Results

The calibration graph drawn for Method 1 can be used to measure the percentage of zinc in a brass except that the percentage obtained must now be multiplied by 10 because the polarogram for the brass has been obtained from only $\frac{1}{10}$ of the zinc precipitate.

Any manganese or lead precipitate in the final solution does not interfere with the definition of the curve or with the size of the diffusion current.

TABLE V.

Number of Sample	Specification or Type	Pb %	Sb %	Cu %	Sn %	Fe %	P %	Ni %	Zinc %		
									Chemical	Polarograph 1	Polarograph 2
1	B.S.S.369	<0·01	<0·02	Rem.	5·64	<0·01	0·145	<0·005	0·015	0·018	0·018
2	B.S.S.369	0·02	<0·02	Rem.	4·50	0·01	0·13	0·005	0·040	0·043	0·043
3	B.S.S.369	<0·01	<0·02	Rem.	5·08	<0·01	0·17	<0·005	0·014	0·013	0·011
4	T.F.F.5 H	0·10	0·02	Rem.	15·0	<0·01	0·69	<0·005	0·050	0·042	0·045
5	T.F.F.5 H	0·13	<0·01	Rem.	15·08	0·01	0·60	<0·005	0·080	0·078	0·083

Method 4 has been applied to the determination of zinc in a wide variety of brasses complying with various specifications with the results shown in Table VI.

Results and Conclusions

Using a drop time of 2·5 seconds, measured without short circuit with the mercury pool anode, very good reproducible curves were obtained.

The accuracy of any of these methods compares very favourably with the accuracy obtained by the classical methods, and in addition, the results are obtained in much less time. Method 2(*a*) especially, by eliminating

TABLE VI.

Number of Sample	Specification or Type	Cu %	Pb %	As %	Fe %	Ni %	Al %	Mn %	Sn %	Zinc %	
										Chemical	Polarograph
1	B.C.S. Brass "B" ..	58·8	0·78	0·03	0·91	1·01	1·62	1·03	1·75	33·9	33·5
2	B.S.S.249	58·4	2·94	—	0·13	0·12	—	0·005	0·31	38·1	38·4
3	B.S.S.251	63·25	0·01	—	0·07	—	—	0·005	—	36·65	36·75
4	B.S.S.1001	57·65	1·13	0·02	0·15	0·03	—	0·80	1·19	39·0	38·6
5	B.S.S.267	69·52	<0·01	—	0·01	—	—	—	—	30·5	30·7
6	Aluminium Brass ..	77·86	0·02	0·03	0·02	—	1·99	0·05	—	20·0	20·2
7	H.T. Brass containing Nickel	55·45	0·02	0·21	0·94	2·82	0·46	0·16	1·33	38·61	38·2
8	T.F.J.5	58·25	—	—	0·07	—	—	0·32	1·00	40·35	39·75

The Chemical figure for the B.C.S. sample is that reported on the certificate of analysis.
The chemical figures for the other samples were obtained by precipitating the zinc as sulphide and igniting to the oxide.

all washing of precipitates or reprecipitations can be completed in half an hour.

However, for bronzes containing a high percentage of nickel it is recommended that the zinc precipitation method be used and, although this method is not so rapid as Method 2, it gives very accurate results providing the tin is first removed as metastannic acid, since it was found that tin inhibits the precipitation of zinc by sodium sulphide from an alkaline cyanide medium. This method was also chosen for brasses in order to eliminate any possible co-precipitation of zinc by the large amounts of aluminium, manganese, and iron present in the final ammoniacal solution when prepared according to Method 2. Also care must be taken when working with brasses or large errors will arise.

Unfortunately, neither method was entirely satisfactory for traces of zinc in copper base alloys, either because of the incomplete removal of the copper or because of the difficulty of precipitating a trace of a substance, so Method 3, which gives a more complete removal of copper, was developed. However, this method is also inapplicable to bronzes containing high percentages of nickel.

A Micro Water Bath

COLSON[1] has described an electrically heated micro water-bath, completely made of glass, which will allow a number of crucibles or similar vessels to be heated simultaneously. The vessels are protected during heating from dust, and any fumes are drawn off by a water-pump. The design of the bath may be followed from Fig. 1.

The steam generator, of 1,500-ml. capacity, is fitted with a 30-ohm nichrome coil (25 BS) with tungsten wire terminals. This is heated from A.C. mains through a Variac transformer. Steam passes from the generator to the holder for the crucibles. This has, in its upper surface, holes of any size required for the work in hand. Alternatively, the holes may be of standard size, and be fitted with a range of adaptors. Holes not in use are closed by ground-glass stoppers.

The steam then passes on through a central column, and is condensed. The condenser, which, to avoid unnecessary height, is spherical, must have a narrowed lower end, to maintain the steam supply round the vessels being heated.

Around the central tube there is a hood which has an upper outlet tube leading to a water-pump. This draws off fumes. Liquid condensing on the inner surface runs down, and is caught in a channel, from which it is drawn off through a lower outlet.

The hood, which fits on by a ground-glass joint, can be moved upwards. Two glass hooks at the top of the hood allow it to be suspended above the heating vessel on two suitably placed wire hooks attached to the condenser stem, when adjustments are being made to the crucibles and so forth. It is seen in this position in Fig. 2.

Ground-joint connections are also made between the steam generator and the heating vessel, the heating vessel and the central column, and the central column and the condenser.

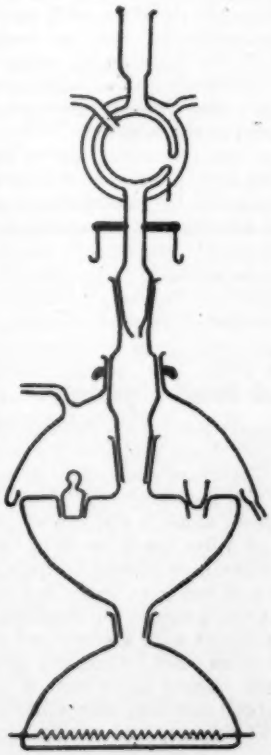


Fig. 1.—Water-bath with hood in position.

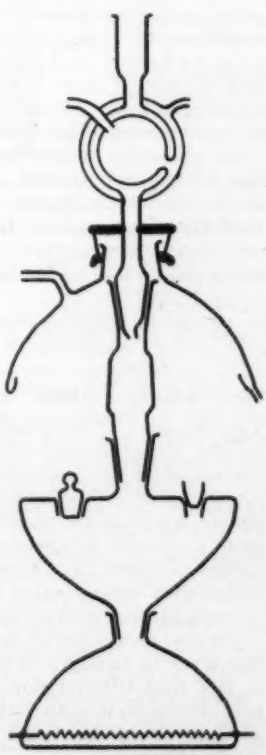


Fig. 2.—Water-bath with hood raised.

1 Colson, *Analyst*, 1946, **71**, 322.

Apparatus in Qualitative Microanalysis

VI.—Apparatus for the Detection of Gases

By R. Belcher

TWO forms of apparatus are generally used on the micro-scale for the detection of gases liberated by the addition of suitable reagents; the Feigl-Krumholz apparatus, [1, 2], in which the reagent is suspended on a knob attached to the bottom of the stopper, and Feigl's modification[3,4], of the Rössler apparatus, in which the stopper consists of a hollow bulb open at each end, the reagent being suspended in the lower tip of the bulb. The latter type is to be preferred for most gas reactions, since the reaction is more easily observed and is generally more rapid than in the Feigl-Krumholz apparatus which has to depend on the slower surface reaction.

The knob apparatus is useful in certain special operations, such as in those reactions where the gas is detected by a reagent consisting of a paste (e.g., the zinc nitroprussic test for sulphur dioxide),[3] or where the amount of gas is so small that some considerable time must elapse for an observable reaction to take place, for then the stoppered apparatus may be left for diffusion to proceed.

Although the Feigl-Rössler apparatus is thus the more suitable for general purposes, it has been found to have one defect; in the detection of traces of those gases which are wholly or partially soluble in the aqueous phase. In this case where the solution must be heated to diminish the solubility, if slight temperature fluctuations occur, the reagent held in the tip of the bulb may sometimes be sucked into the apparatus. This has been found to happen in determining the limits of identification of certain tests when extremely dilute solutions were being used, necessitating a long period of heating to expel traces of gas dissolved in the solution.

To overcome this nuisance the apparatus shown in Fig. 1D has been devised. The drop of reagent is placed at the bend between the two bulbs by means of a fine capillary. During the initial heating, the expanded air passes through the reagent as in the Feigl-Rössler apparatus. If a sudden cooling effect causes contraction of the air remaining in the apparatus, the drop of reagent is drawn into the first bulb until, reaching the wide portion, it collapses and falls back into the bend. By this means, all risk of the reagent being sucked into the body of the apparatus is avoided and the test may be left indefinitely without attention.

The apparatus may be constructed as follows: Draw out a piece of tubing about 8 mm. in diameter as shown at Fig. 1A and cut at the points a, a_1. Heat bulb b at the point shown and draw out to give two smaller bulbs

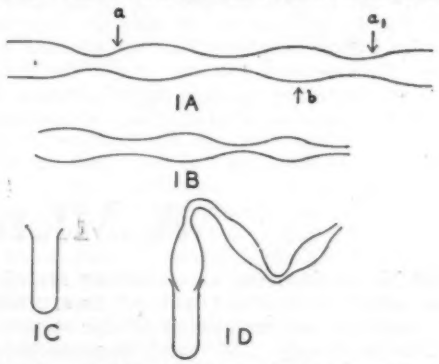


Fig. 1.—Construction of the two-bulb apparatus.

(Fig. 1B). Seal a piece of tubing about 6 mm. in diameter, at one end cut to a length of 2·5 cm. and widen the open end as shown in Fig. 1C. Grind the larger bulb into the mouth of the sealed tube with a paste of carborundum and water and finally bend the top portion as shown in Fig. 1D.

This apparatus is only recommended for the special purpose for which it was devised, since the Feigl-Rössler apparatus is equally satisfactory for all other purposes and the method of introducing the reagent is simpler.

Chemistry Department, Marischal College, Aberdeen.

1 Feigl and Krumholz, *Mikrochemie, Pregl Festschrift*, 1929, 83.
2 Belcher and Burton, METALLURGIA, 1945, **31**, 272.
3 Feigl, *Qualitative Analysis by Spot Tests*, Trans. by J. W. Matthews, Amsterdam, 1937.
4 Belcher and Wilson, *Qualitative Inorganic Microanalysis*, Longmans, Green & Co., Ltd., London, 1946.

Fuel, Power and Heat Costing

THE Ministry of Fuel and Power has issued *Bulletin* 48 on the above subject. It has been prepared for the assistance of managements, engineers and others as an introduction to fuel, power and heat costing. It is, of course, appreciated that costing alone is not the whole story; everything depends on what use is made of the figures obtained. Planning depends on costing and, also, progressive deterioration in fuel and heat usage can be more easily detected if comparative figures are available. Costs can be compared department with department or factory with factory. While it may not be literally true to say that without adequate costing there cannot be fuel efficiency, it is an undoubted fact that where intelligent use is made of the cost figures, fuel savings are made easier.

When the need for a costing system has been realised, the works' manager will have to ask himself how it is to be put into operation and how it is to be used. Some of the questions that may occur to him are:

1. How frequently should costs be ascertained?
2. What technical data are necessary and how can they be collected most conveniently?
3. What should a cost statement include?
4. What method of costing steam to users should be adopted?
5. Are there similar plants in my neighbourhood whose costing systems I could inspect as a basis for comparison?
6. Shall I employ a qualified costing clerk?
7. Can the auditors help, or could they suggest people whom I might consult?

This Bulletin is being generally circulated and additional copies are available free on demand from the Ministry's Regional Offices.

The Melting of Molybdenum in the Vacuum Arc

By R. M. Parke and J. L. Ham

THE melting point of molybdenum is 2625° ± 50° C., and so far the metal has been considered too refractory to be melted in commercial quantities, with the result that it has been formed into rod, wire and sheet by powder metallurgy methods, wherein the temperatures do not exceed 90% of the melting temperature. To overcome the inherent disadvantages of the powder metallurgy method, especially in respect of the limit of size, investigations were begun in 1943 at the Climax Molybdenum Co.'s laboratory to develop a method of melting and casting molybdenum, capable of producing larger bodies of molybdenum than were then obtainable. As a result of these tests, methods of melting and casting molybdenum are now described, with details of the special process required to make molybdenum castings ductile and a report of some of the properties of what may be regarded as a new, or at least modified, form of the metal.

Experiments showed that molybdenum can be cast into a water-cooled copper mould without melting the mould, and that a water-cooled copper wall, ¼ in. thick, can absorb the radiant energy of a 20 volt., 40 kw. arc at a distance of ¼ in. without vapourisation of copper in any amount detectable in the product. These facts made possible the combining of the melting chamber with the casting mould, and the adoption of a simple arc arrangement, Fig. 1, in which there is an upper, vertical, consumable, solid electrode, opposed to a lower, liquid electrode. The upper electrode was made up of a series of pressed and sintered molybdenum bars joined with molybdenum nipples. The lower electrode, through solidification, was gradually converted into the casting. The arc was controlled by lowering the upper electrode. Drops of molybdenum formed at the lower end of this electrode and fell into the liquid pool below at the rate of 6 to 8 grams per second, or about 50 lb. per hour, and 25 lb. was the weight limit of castings produced. To deoxidise the molybdenum and render it forgeable, 0·01% of carbon was added during the melting practice. Not more than one kilowatt-hour was required to melt and deoxidise one pound of molybdenum.

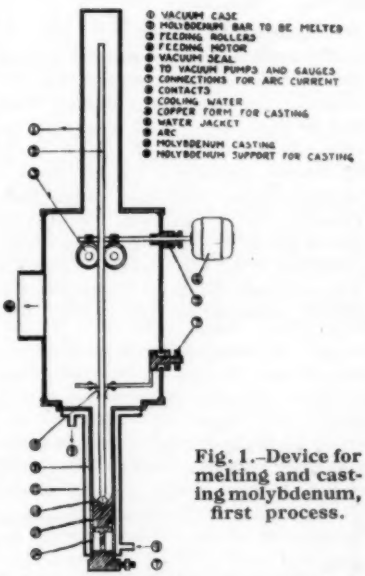


Fig. 1.–Device for melting and casting molybdenum, first process.

Hot-working of arc-cast molybdenum was carried out by heating the cast bars in vacuum by induction heat to the forging temperature, 1400° to 1550° C. They were then withdrawn into air and worked in a two-die swage, the dies of which were forced together on a 750-lb. air hammer. The dies were designed to place a large portion of the bar under hydrostatic pressure and thus have an action similar to that of extrusion.

The average density of the castings was 10·17 and the density of cast and wrought molybdenum (after 85% reduction of area) was 10·22, most of the difference being due to gas holes resulting from incomplete oxidation. The surfaces of the castings, formed by the water-cooled copper mould, were rough and for most purposes ⅛ in. required to be machined off. A non-metallic grain boundary constituent, which is usually present in powder metallurgy molybdenum, had to be absent from vacuum arc-cast molybdenum, if it was to be readily hot-swaged. It was also found that cast molybdenum fully deoxidised could contain at least as much as 0·06% carbon without losing hot-workability. The crystals of cast molybdenum were not equiaxed but were long, slender and curved, and the grain size decreased with diameter of casting and was dependent upon purity. The grain size after hot working varied between 0·05 and 0·1 mm. in diameter.

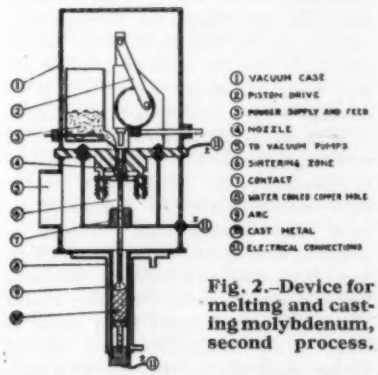


Fig. 2.–Device for melting and casting molybdenum, second process.

As the preparation of the consumable electrode was difficult, as it required the individual pressing and sintering of molybdenum bars and then their joining, another process was devised. In this second process, five distinct operations, all in vacuum, were co-ordinated to form automatically a molybdenum casting from powder. These were: (1) pressing the molybdenum powder into a continuous rod; (2) partially sintering the rod by electrical resistance heating; (3) melting the end of the rod in the electric arc; (4) deoxidising the molten molybdenum with carbon added to the powder; and (5) casting

From *Metals Technology* 1946, Vol. 13, No. 6 and *A.I.M.M.E. Tech. Public. No.* 2052, pp. 1–12.

in a water-cooled copper mould. The continuous pressing of the rod of molybdenum was done in a manner similar to pelleting, except that each new pellet was pressed upon its predecessor in a cylindrical mould. The lower and hotter part of the sintering zone was controlled at a temperature of 1500° C. by a photoelectric device. After the sintered rod passed the lower contact it was found to be strong enough to suspend itself from the contact and reach downward to the bottom of a water-cooled copper mould. At the bottom of the mould an arc was formed, and from this point onwards, the melting deoxidising and casting were similar to the same three operations in the first process. A sketch of the apparatus in which the second process was conducted is given in Fig. 2.

Heat-Treatment and Stabilisation of High Carbon Stainless Steel

By H. E. Boyer and H. C. Miller

A LARGE amount of research work has been carried out on the heat-treatment of several types of martensitic stainless steels. The present investigation was confined to a steel containing 1·0% carbon, 17·0% chromium and 0·5% molybdenum, and was undertaken to obtain heat-treatments for this steel which would not only obtain maximum hardness and wear resistance but would also develop a high resistance to corrosion, maximum toughness and stability, which is necessary in the manufacture of precision parts. Such a steel retains high percentages of the gamma phase after being cooled from the austenitising temperature, and this condition not only prevents maximum hardness from being obtained, but also leaves the heat-treated parts in a state of dimensional instability. By use of higher austenitising temperatures than normal, a greater percentage of carbon is dissolved in the austenite, resulting in a higher initial hardness as well as a higher seconding hardness. A low temperature treatment immediately after quenching causes a great deal of the gamma phase formed to be transformed.

Test specimens, 2 in. by 0·575 in., were austenitised at 980°, 1010°, 1040°, 1065° and 1095° C. in a high temperature furnace in a highly reducing atmosphere and cooled in air or quenched in oil. Low temperature treatment at −85° C. immediately after cooling or quenching was carried out in a " Deep-freeze " unit, using air as a medium in preference to liquid. Tempering after air cooling and oil quenching with or without a low temperature treatment, was carried out over a range from 150° to 565° C. Hardness/tempering curves were drawn for each austenitising temperature. Typical curves obtained for air cooling and oil quenching at 1065° C. are shown in Figures 1 and 2.

The results obtained showed that as the austenitising temperature was increased, the hardness obtained from the as-quenched pieces was also increased, and that in most cases specimens quenched in oil showed slightly higher hardness values than those cooled in still air. Relatively sharp secondary hardness peaks were obtained in all the curves. The peak for secondary hardness for an austenitising temperature of 980° C. was obtained by tempering at 455° C., and for an austenitising temperature of 1095° C. by tempering at 480° C. The effects of low temperature treatment were more noticeable as the austenitising temperature was increased.

To obtain more data on this type of steel, test specimens were austenitised over a range of temperature from 980° to 1200° C. in 25° C. steps and a curve obtained showing the percentage of austenite retained after quenching from the various temperatures in this range, as well as the amount that could be transformed by treating at −85° C. and subsequent tempering at 480° C., which was the temperature assumed to show maximum secondary hardening properties. Specimens austenitised at 1175° C. or higher were found to be 100% austenitic after quenching. Low temperature heat-treatment and subsequent tempering caused a transformation of only about 30% of the total volume, and such changes were confirmed by micro-examination. Specimens tempered at 480° C. immediately after quenching, then subjected to −85° C., followed by retempering at 480° C., showed no further structural changes.

Impact test values were obtained on specimens air cooled from 1065° C. Specimens were tested in the as-quenched condition, as well as after quenching and subjecting to −85° C. Other specimens austenitised in the same way were tempered over the range 150° to 565° C. It was found that lower impact values were obtained in specimens subjected to the low temperature treatment and that the relatively sharp secondary hardness peak which was obtained by tempering at 480° C. was immediately followed by a sharp drop in impact value, thus suggesting that temper brittleness was present in specimens tempered at 510° C. for a 1065° C. austenitising temperature. After tempering at 540° C., the impact value increased rapidly as the hardness decreased.

In general, the investigation has shown that for the type of steel tested, the most satisfactory heat-treatment is austenitising at 1065° C. in a protective atmosphere, cooling in still air, followed by cooling in a medium of air to −85° C. and a final double tempering at 480° C. Such a treatment will produce parts that are consistently 57 to 60 Rockwell C. hardness, and which possess good resistance to wear, dimensional stability and a high resistance to most forms of corrosion.

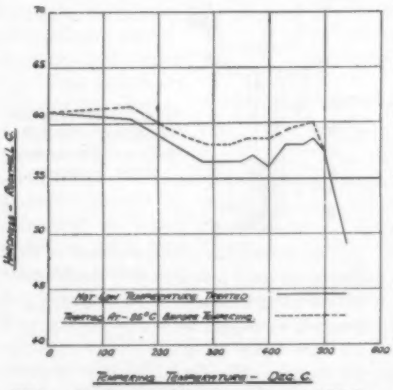


Fig. 1. Austenitised at 1065° C., cooled in air and tempered as shown.

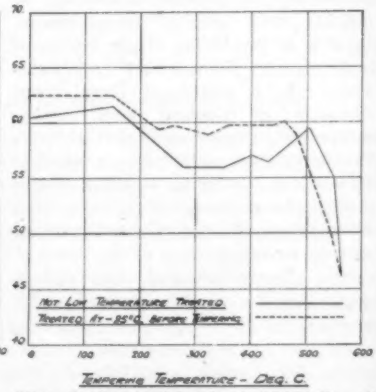


Fig. 2. Austenitised at 1065° C., oil quenched and tempered as shown.

From *Materials and Methods*, 1946, Vol. 24, No. 3, pp. 637–641.

Properties of Cerium-Containing Magnesium Alloy at Room and Elevated Temperatures

By T. E. Leontis and J. P. Murphy

THE results of an extensive investigation on the properties of various cerium-containing magnesium alloys in both the cast and forged conditions are reported. Data are presented to show the beneficial effects of increasing amounts of cerium on the mechanical properties of magnesium at elevated temperatures, and the effects of heat-treatment on the properties of these alloys and the changes that occur in microstructure by such treatment, are also considered. The alloys investigated are given in Table I, together with their corresponding A.S.T.M. designations. In all the alloys cerium was added as an alloy (Mischmetal), containing 45–50% cerium, 22–25% lanthanum, and 23–27% other rare earths, and throughout the investigation the term "per cent. cerium" refers to the total rare earth content of the alloys.

Magnesium containing 6–10% cerium sand-cast at 760° C. in the form of standard 0·5-in. test bars, has a moderately fine equiaxed grain size of 0·01–0·04 in. which is not influenced by subsequent heat-treatment. The grain size can be markedly changed, however, either by the manganese content or the pouring temperature. Additions of manganese up to 2% show a progressive increase in grain size up to a value of 0·20 in. Increase in pouring temperature from 650°–815° is accompanied by an increase in grain size from 0·02–0·15 in.

TABLE I.—Nominal Composition of Cerium-Containing Magnesium Alloys

Alloy Designation	Ce	Mn
E6	6	—
E10	10	—
EM 02	0·5	2
EM 22	2	2
EM 42	4	2
EM 62	6	2
EM 102	10	2

Tensile tests at room and elevated temperatures were carried out on the cast test bars without machining the as-cast surface. Fatigue tests were determined on R. R. Moore's rotating-beam machines, using plain and notched specimens with a highly-polished surface. Creep results are based on tests of 100-hour duration carried out on individual creep machines. The electrical conductivity was determined from resistance measurements made with a Kelvin bridge in a constant-temperature room at 35° C., and the values determined corrected to 20° C. The corrosion rates were based on alternate immersion tests in 3% sodium chloride solution at 35° C. for a period of 14 days unless complete solution took place earlier. In Table II are given the results of tensile and creep tests over the range room to 315° C. for the magnesium-cerium alloys E6 and E10, and also fatigue tests at room temperature and 150° C. for the same alloys.

The results of the tests show that additions of cerium to magnesium produce alloys that retain relatively high strength and hardness at temperatures up to 205° or 260° C., and that increasing amounts of cerium increase the elevated temperature strength and hardness. The creep resistance of cerium-containing magnesium alloys is superior to that of other known magnesium alloys at elevated temperatures. Heat-treatment and ageing of magnesium alloys containing cerium between 205° and 370° C. increase the electrical conductivity of the alloys and also their dimensional stability. The effect of heat-treatment and ageing is pronounced in the case of creep resistance at 150° and 205° C.

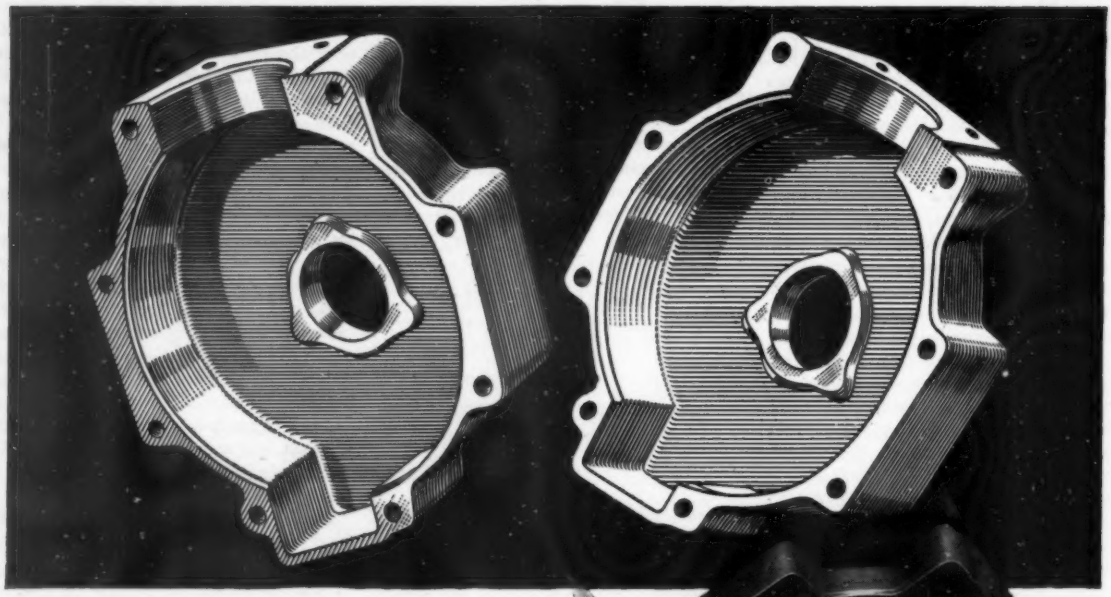
The strength properties of magnesium-cerium alloys containing manganese up to 2% show a marked increase with increasing cerium content and the effect is more pronounced at elevated temperatures. Alloys containing 6 and 10% of cerium and 2% of manganese are most satisfactory in retaining higher strength and hardness over a wide temperature range, and increasing the cerium content from 6–10% in such alloys results in higher strength and hardness. Manganese also increases the solid solution of cerium in magnesium at heat-treating temperatures, and additions of manganese of over 1·1% markedly improve the corrosion resistance of magnesium-cerium alloys in 3% sodium chloride solution.

From *Metals Technology*, 1946, Vol. 13, No. 3, and *A.I.M.M.E. Technical Publication*, 1995, pp. 1–32.

TABLE II.—Properties of Sand-Cast Cerium-Containing Magnesium Alloys at Room and Elevated Temperatures

Temperature °C.	Alloy	Heat Treatment	Yield Stress Tons/sq. in.	Ultimate Stress Tons/sq. in.	Elong. %	Brinell Hardness	Creep Limit Tons/sq. in.	Fatigue Properties. Tons/sq. in.					
								10^8 Cycles			10^8 Cycles		
								Sp	Sn	NF	Sp	Sn	NF
Room	E6	SCS	6·3	7·9	1·0	50·7	—	4·2	3·8	0·84	2·2	1·8	0·80
	E6	HTA	7·2	9·4	0·5	58·2	—	6·0	4·9	0·81	4·0	2·7	0·67
	E10	SCS	—	7·2	0·0	63·6	—	5·4	4·0	0·75	4·9	2·2	0·71
	E10	HTA	—	8·6	0·5	69·0	—	6·0	4·5	0·74	4·7	3·6	0·76
150	E6	SCS	4·6	4·7	2·5	41·3	4·7	3·8	3·1	0·82	1·8	1·1	0·62
	E6	HTA	7·1	6·3	3·0	48·3	6·3	6·0	3·6	0·59	3·6	2·0	0·56
	E10	SCS	6·5	5·7	0·0	51·8	5·7	4·5	3·1	0·82	2·9	1·6	0·54
	E10	HTA	7·3	8·2	1·0	58·3	8·2	5·8	4·5	0·77	4·0	2·9	0·72
205	E6	SCS	4·1	8·3	6·0	36·9	—	—	—	—	—	—	—
	E6	HTA	7·6	8·4	3·5	46·4	—	—	—	—	—	—	—
	E10	SCS	5·6	7·6	1·0	48·3	4·1	—	—	—	—	—	—
	E10	HTA	7·2	8·7	1·8	54·7	4·6	—	—	—	—	—	—
260	E6	SCS	3·7	8·4	6·2	35·2	—	—	—	—	—	—	—
	E6	HTA	3·9	7·2	10·7	40·2	—	—	—	—	—	—	—
	E10	SCS	4·8	7·5	1·3	43·0	1·8	—	—	—	—	—	—
	E10	HTA	6·4	8·2	2·0	42·0	2·0	—	—	—	—	—	—
315	E6	SCS	2·6	5·8	40·0	26·1	—	—	—	—	—	—	—
	E6	HTA	3·0	5·1	41·7	24·8	—	—	—	—	—	—	—
	E10	SCS	3·5	7·0	2·5	34·0	0·8	—	—	—	—	—	—
	E10	HTA	4·2	7·2	7·2	37·6	1·0	—	—	—	—	—	—

S.C.S.—Sand Cast Stabilised. H.T.A.—Heat-treated and Aged. Sp.—Plain. Sn.—Notched. NF.—Notch Factor = $\frac{Sn}{Sp}$



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MAGNESIUM ALLOYS

In general, the conductivity of cerium-containing magnesium alloys is markedly higher than any of the presently used commercial magnesium alloys, with the exception of Dow-metal M.

Calculation of Tensile Strength and Yield Point from Chemical Composition and Cooling Rate

By I. R. Kramer, P. D. Gorsuch and D. L. Newhouse

ALTHOUGH many methods have been suggested for the calculation of tensile strength and yield point from chemical composition, their usefulness has been limited to a particular cooling rate or section size. Further limitations have been imposed by failure to take into account many of the alloying elements that exert a considerable influence on the tensile strength or yield point. The purpose of the present investigation is to present a method of calculating tensile strength and yield point from the chemical composition and to suggest a method of correlating the tensile-strength and yield-point factors and cooling rate.

The steels used in the investigation were melted in a 300-lb. high-frequency induction furnace, and the various heats were usually split into five parts and the appropriate alloying additions were made in the furnace before the steel was poured into a cast-iron ingot mould. Some heats were deoxidised with aluminium, but in general the heats were silicon-killed. After soaking for 10 hours at 1,260° C., the ingots were rolled into plates $\frac{3}{4}$ in. thick. For $\frac{5}{8}$-in. plates, parts of the $\frac{3}{4}$-in. plates were further reduced by forging to plates 6 × 6 × $\frac{5}{8}$ in. Before heat-treating, tensile bar blanks were cut from the $\frac{3}{4}$-in. plate, which were machined after heat-treating. The tensile bars of the $\frac{5}{8}$-in. plate were taken from the centre section after the heat-treatment of the plate. After the specimens were austenitised for 2 hours at 845° C., they were cooled at various rates. The cooling rates used for the calculation of the factors approximated to the cooling rates at the centres of air-cooled $\frac{5}{8}$-in., 4$\frac{3}{4}$-in., 18-in. and 28-in. plates.

A steel used in the determination of the effect of austenitic grain size was given special austenitising treatments in order to develop a range of grain sizes. The specimens were austenitised at various temperatures from 845°–1,150° C. for 2 hours, then rapidly transferred to a furnace at 845° C. and cooled at a rate approximating to the cooling rate at the centre of an air-cooled 18-in. plate. A steel free from strong carbide-forming elements was selected for the grain-size experiments.

Using different series of steels, tensile-strength and yield-point fracture curves were determined for carbon, manganese, silicon, phosphorous, sulphur, nickel, chromium, molybdenum, titanium, vanadium and aluminium. Curves were also obtained showing the effect of cooling rates on the tensile strength and yield-point factors of the various elements. A typical tensile strength factor curve and cooling rate curve for manganese are given in Figs. 1 and 2.

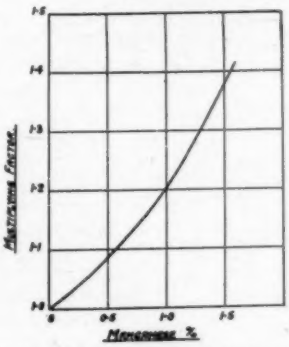

Fig. 1.– Tensile strength factor for manganese, No. 1 cooling rate.

By means of the factor curves obtained, it was found possible to calculate with reasonable accuracy, the tensile strength and yield point of steels cooled at rates between those at the centre of a $\frac{1}{2}$-in. plate and those at the centre of a 16-in. plate. If the half-temperature time was known, the tensile strength and yield point at any position in the test piece might be calculated. The most effective combination of alloying elements for a desired tensile strength and yield point might be obtained by examining the individual factor curves for the particular cooling rate involved. As some of the alloying elements did not influence the tensile strength in the same manner as the yield point, a judicious choice of alloying elements had to be made in order to achieve a definite yield-tensile ratio in the most economical manner. To make more efficient use of alloying elements in steel, the multiplying factor curves should be closely examined with respect to their shape as well as their magnitude. Many of the alloying elements, such as phosphorous, titanium and vanadium, contributed markedly to both tensile strength and yield point at low percentage, while small percentages of molybdenum and copper increased it only slightly, but in larger amounts had a large effect.

When fairly large amounts of low-temperature transformation products of austenite were formed during cooling, it was found that the factor curves developed were not adaptable for the calculation of tensile strength or yield point. Also the yield strength at 0·01% offset of steels that did not have a definite yield point could not be calculated with any reasonable degree of accuracy unless the corresponding tensile strength could also be calculated. Results obtained from five steels showed that the factor curves might be used for normalised cast steel as well as wrought steel.

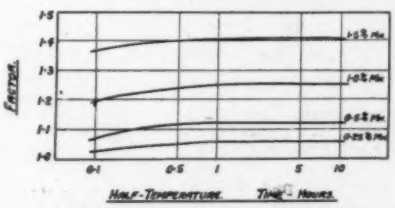

Fig. 2.—Effect of cooling rate on tensile strength, for manganese.

From *Metals Technology*, 1946, Vol. 13, No. 6, and *A.I.M.M.E. Tech. Public.* No. 2067, pp. 1-28.

The Use of Ultra-Fine Particles in Powder Metallurgy

By H. H. Hausner

THE effects of particle size and particle-size distribution on the physical properties of powder metallurgy compacts are well known. Particle or grain size in powder metallurgy is usually expressed in terms of "mesh-size," indicating thereby the results of a screen analysis. Generally, particle size is indicated by showing the percentage of powder retained on each of several mesh sizes (100, 150, 200,

From *Materials and Methods*, 1946, Vol. 24, No. 1, pp. 98–102.

TABLE I.
PROPERTIES OF PRESSED AND OF SINTERED COMPACTS MADE FROM DIFFERENT PARTICLE-SIZE MIXTURES.

No.	Particle Size Distribution	Pressing Pressure Tons/sq. in.	Properties				
			After Pressing		After Sintering		
			Volume CC	Density G/CC	Volume CC	Density G/CC	Rockwell Hardness
A 1 ..	Cu, 100% 2 microns	5	2·99	4·95	1·92	7·72	29 H
2 ..		10	2·69	5·54	1·91	7·80	38 "
3 ..		20	2·38	6·29	1·89	7·95	51 "
4 ..		30	2·08	6·94	1·76	8·18	61 "
B 5 ..	Cu, 100% 44–74 microns.	5	2·77	5·38	2·26	6·58	<1 "
6 ..		10	2·40	6·07	2·06	7·04	12 "
7 ..		20	2·15	6·88	1·93	7·67	31 "
8 ..		30	1·91	7·65	1·83	7·98	42 "
C 9 ..	Cu, 47% 2 microns; 53% 44–74 microns.	5	2·74	5·48	2·10	7·15	23 "
10 ..		10	2·84	5·47	2·06	7·48	36 "
11 ..		20	2·12	6·89	1·81	8·05	47 "
12 ..		30	1·95	7·64	1·74	8·45	54 "
D 13 ..	Cu, 47% –325 mesh; 53% 44–74 microns.	5	2·74	5·40	2·09	7·10	20 "
14 ..		10	2·56	5·71	1·98	7·37	33 "
15 ..		20	2·24	6·82	1·83	7·99	43 "
16 ..		30	1·96	7·66	1·80	8·31	52 "
17 ..	Cu, 2 microns; Sn, 44–74 microns.	5	2·45	5·06	1·97	6·24	26 T
18 ..		10	2·04	5·75	1·86	6·24	
19 ..		20	1·84	6·52	1·86	6·34	
20 ..		30	1·67	7·01	1·81	6·40	33 T
21 ..	Cu and Sn 44–74 microns.	5	2·07	5·90	1·98	6·12	14 T
22 ..		10	1·86	6·45	1·92	6·18	
23 ..		20	1·70	7·25	1·99	6·13	
24 ..		30	1·57	7·65	1·99	6·04	17 T
25 ..	Cu, 2 microns; W, 44–74 microns.	5	3·07	6·42	2·25	8·75	48 H
26 ..		10	2·62	7·50	2·21	8·90	57 "
27 ..		20	2·38	8·54	2·22	9·07	67 "
28 ..	Cu and W 44–74 microns.	5	2·80	7·04	2·47	7·97	24 "
29 ..		10	2·42	8·25	2·30	8·65	38 "
30 ..		20	2·16	9·25	2·40	8·30	40 "
31 ..	Cu, 2 microns; W –325 mesh.	5	3·08	6·33	2·30	8·40	51 "
32 ..		10	2·75	7·20	2·28	8·59	54 "
33 ..		20	2·21	8·24	2·03	8·94	59 "
34 ..	Cu, 44–74 microns; W –325 mesh.	5	2·94	6·82	2·67	7·30	14 "
35 ..		10	2·42	7·88	2·29	8·25	31 "
36 ..		20	2·22	8·78	2·19	8·80	41 "

250, 325), ending with some large percentage finer than 325 mesh. This method of specifying the particle size could almost be called precise, if it did not contain this last term " minus 325 mesh size," which gives no indication about the actual size and distribution of the particles thus classified. The shrinkage of metallurgy compacts depends on particle size, particle-size distribution, compacting pressure, pressure distribution, sintering temperature, time and atmosphere. The compacting and sintering conditions can be controlled without difficulties, but particle size and particle-size distribution can never be the same as long as powders of —200 mesh or —325 mesh size are used.

The effect of particle size on the density breaking stress, elongation and hardness of a sintered material has been determined out by testing a bronze compact containing 90 parts copper, 10 parts tin, 2 parts graphite. The powders which were compacted at 20 tons/sq.in. had the following mesh sizes :—

The fine powders were :—
100% of –325 mesh size.

The medium powders were :—
67% of –325 mesh size.
33% of –100 mesh size.

The coarse powders were :—
33% of –325 mesh size.
67% of –100 mesh size.

It was found that density, breaking stress, and hardness decreased with increasing particle size, whereas the elongation increased.

It has also been found that loosely-heaped powder particles of spherical shape of the same diameter will arrange themselves in different ways. Metallic powders, when placed in a compacting die, fill the space only to a certain degree and a certain amount of voids are present. To compact the powders and to eliminate or to diminish the pores of the compact, the particles have to be formed or worked and a fairly high pressure is necessary for such deformation. If, however, the voids between the coarse powder particles are filled with powders of smaller size, much less deformation of the large particles is necessary to obtain a dense material, and a much lower pressure may be applied for the compacting process.

A new type of ultra-fine copper powder has been developed and its use for powder metallurgy has been studied. The particles of this powder are round, although not quite spherical and of a size between 0·3–3 microns. The average particle size is 2 microns, with 90% of the powder of this size, and the powder is specified to be of 99·4% purity. Compacts were made of this powder and compared with compacts made from electrolytic copper powder of 200 to 325 mesh size (called 44–74 micron powder) and also with mixtures of different particle sizes. Four series of tests were carried out and compacted at 5, 10, 20 and 30 tons/sq. in. The compacts were then sintered in hydrogen at 800° C. for 1 hour and at 900° C. for 1 more hour. In Table I are given the properties of the samples in their compacted and sintered conditions.

Samples made with 2 micron powder showed a low density in the compacted state and a fairly high density in the sintered state. During the sintering period the percentage density increases of the compacts made from ultra-fine powders was very high. At low pressure the highest density was obtained by using the 2 micron powder and at high pressure the greatest density was achieved by using a mixture of 47% particles of the 2 micron size and 53% of 44–74 micron size. The greatest hardness was obtained with samples made entirely of the 2 micron powder.

In two other test series the effect of particle size on the properties of a mixture of 90% copper and 10% tin was determined using different particle sizes. The results given in Table I, samples 17–24, showed that the particle-size distribution was of no substantial influence on the density although the samples made with ultra-fine copper particles were of slightly greater density. The particle size of copper-tin samples made of ultra-fine copper powder, however, showed an almost 100% greater hardness than the samples made of coarse copper powder.

To study the effect of ultra-fine copper particles mixed with an extremely hard powder, tests were made with copper tungsten mixtures, Table I, samples 25–36. These tests showed that the density of sintered samples was much greater when ultra-fine copper powder was used and that after sintering a decrease in density occurred when coarse particles were compressed at the high pressure. Hardness of samples made with ultra-fine copper particles was also much greater than the hardness of samples made with coarse copper particles.

BE